GEOL 1008 Study Notes

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Rocky Worlds

The study of rocks

Geology is the study of rocks.
This means that interplanetary geology (studying rocks from other planets) is still geology.
Geologists are an important part of the study of other planets due to their understanding of the way rocks work.
There are several rocky planets/objects in our solar system that geologists can study:

- The four rocky planets: Mercury, Venus, Earth and Mars
- The Dwarf planets: Eris, Pluto
- The Moons
- Asteroids and comets

We have direct samples of several rocky bodies, including the Moon, Mars, Earth, Vesta, and Itokawa.
Earth is the largest of all of these rocky bodies.

The Rocky Planets

Planets in our solar system differ radically from one planet to another in size, orbit and composition.
The inner planets (Mercury, Venus, Earth, and Mars), are the planets closer to the Sun, are relatively small.
They are also called the terrestrial planets because, like the Earth, they consist of a solid outer shell of rock surrounding a often molten ball of metal.
The outer Planets (Jupiter, Saturn, Uranus, and Neptune) are known as the giant planets, or Jovian planets.
The largest, Jupiter, contains 318 times as much mass as the Earth and accounts for about 71% of the non-solar mass in the Solar System.
The overall composition of giant planets differs markedly from that of terrestrial planets.
Specifically, most of the matter in Jupiter and Saturn consists of hydrogen and helium as a gas, liquid, or as a strange liquid-metal state.
Because so little solid material occurs in these planets, astronomers refer to them as gas giants. In contrast, most of the matter in Neptune and Uranus consists of water, carbon dioxide, and methane that has been frozen into solid ice.
Because so much ice occurs in these planets, astronomers call them ice giants.
(Earth: A Portrait of a Planet)

Other Rocky Celestial Bodies

In addition to planets, the Solar System contains a great variety of other rocky objects:
Moons:

- A moon is a solid object, of detectable size, that orbits a planet. All planets except Mercury and Venus have moons.
- We have one moon (very creatively named), Mars has two Phobos and Deimos, Jupiter has at least 63, and Saturn has at least 62. Moons vary greatly in size, composition, and surface characteristics.
- Some moons are made up of mostly rock, and others mostly ice.

- Some have surfaces pockmarked by the impact of meteorites billions of years ago, while others have been resurfaced by materials erupted from volcanoes or geysers.

Asteroids:

- An asteroid is a relatively small, rocky or metallic object that orbits the Sun
- Most of them are found between the orbits of Mars and (Due to the condensation sequence of rocky material)
- They range in diameter from 1 cm to 930 km.

Kuiper Belt and Oort Cloud Objects:

- About a trillion bodies of ice, with diameters ranging from less than 1 cm to 2,000 km, lie outside the orbit of Neptune.
- They occur in a donut-like ring closer in comprise the Kuiper Belt.
- More distant ones form the Oort Cloud, which has a slightly spherical shape.
- Most of these icy objects are tiny being a few centimetres across but some are much larger.

Duarf Planets:

- Asteroids and Kuiper Belt objects with a diameter greater than about 900 km are known as dwarf planets.
- Though only five have yet been identified, there may be up to 200 dwarf planets.
- The largest known dwarf planets are Eris and Pluto

Comets:

- Kuiper Belt or Oort Cloud objects that follow elliptical orbits that bring them into the inner Solar system are called comets.
- Comets are made up of ice and dust giving them the colloquial name ‘dirty snowballs’
- When they fly close to the sun, they gain a tail formed by the evaporating ice

(Earth: A Portrait of a Planet)

The condensation sequence

The planet’s distance from the proto-sun constrains the planet’s composition during the formation of a solar system.
Only high-temperature materials like tungsten, aluminium oxide, iron, and silicates could condense close to the Sun, forming planets like Mercury and Venus.
Farther out, carbon-rich silicates and ices could condense, forming gas giants and icy bodies like Saturn, Uranus, Neptune, and comets.

The Recipe for a Solar System

The solar system’s formation begins with a nebula that undergoes gravitational collapse, creating a proto-sun and protoplanetary disk.
As the protosun heats up, it undergoes nuclear fusion.
The protoplanetary disk starts to take shape as gasses condense and metals and rocks start clumping together.
The terrestrial planets undergo accretion, and ice and gasses are captured to create Jovian planets.
The materials left at the end of this process become asteroids and comets.

How do we know this

We can tell this by looking at HL Tauri
HL Tauri is a planetary nebula 450 light years away
We can observe the planets clearing their orbits
Proving that the planetary accretion hypothesis is correct

Exploration of the solar system

We have explored a large amount of our solar system though sending out space crafts and landing probes to different celestial bodies
We can also infer the history of the solar system through samples we have collected from different celestial bodies

The Rocky Bodies

Mercury

- first planet from the sun
- It does not have an atmosphere
- The surface temperatures range from -173 to 427°C
- It is heavily cratered from asteroid impacts
- It has an iron core
- It is made of basalt
- The core is 1,800km thick, the mantle is 600km thick, and the crust is 100-200km thick
- It is 38% the size of Earth
- Mercury has no plate tectonics, meaning that it is shrinking, forming surface compression features.

Venus

- second planet from the sun
- It has an atmosphere of thick CO_2
- The surface temperatures are around 470°C
- It has 92 times the surface pressure of the Earth
- It has sulfuric acid clouds
- It has very few craters
- It is made of basalt
- It may have surface volcanism still
- It is 5% smaller than Earth

Mars

- fourth planet from the sun
- It has a thin CO_2 atmosphere
- The surface temperatures range from -153 to 20°C
- It is 0.6% times the pressure of the Earth's atmosphere
- It contains Olympus Mons and Valle Mariners
- Lots of probes have landed on Mars, so we have lots of pictures and rock analyses.
- Mar's surface contains a mix of igneous and sedimentary rocks
- It has shown past signs of water
- We have meteorite samples of Mars

Io

- Moon of Jupiter
- Like all of Jupiter’s moons it was named after an affair Jupiter had with his wife Juno
- The surface temperatures are around -163°C
- It has more than 400 active volcanoes
- It has a thin layer of sulphur dioxide as its atmosphere, but it is constantly lost to space
- It is made of Basaltic Rocks

- It has a silicate surface with high amounts of sulphur

Titan

- Titan is a moon of Saturn
- The surface temperatures are around -173°C
- The atmospheric pressure is 1.5 times that of Earth and is made of nitrogen, ethane and methane
- The planet has lakes of methane
- It also has cryovolcanic activity

Chondrites and the age of the solar system and the Earth

Chondrites are a form of primitive meteor that was leftover after the formation of the rest of the solar system
All of the chondrites that we have dated have the same U-Pb dating age
The age of the chondrites proves that the solar system and therefore earth is 4.57Ga
This also shows that the solar system and earth are 1/3 the age of the universe which is estimated to be around 13.8Ga

Meteorites from Mars

We have samples of mars that we have collected from asteroids
These have formed as meteorites from the surface of mars have been ejected during large asteroid impacts
We can tell these meteorites are from mars as they have the same chemical composition as measured on mars as well has having the same atmospheric composition
We can tell this as a small part trapped in tiny bubbles inside the meteorites, which is the same composition as measured by the Vicking rover in 1976
We have 132 meteorites from mars
All of them are basalts/mantle
Some are as old as4.5Ga

Asteroid Vesta

Vesta is an asteroid with a diameter of 530km
It is the second largest asteroid in the asteroid belt
It had active volcanism for the first 30Ma after its formation
It is covered in basalt
It was orbited by the Dawn mission in 2011
HED (Howardite, Eucrite, Diogenite) meteorites are through to been created by vestas volcanism

The Moon

We have a huge number of samples of the moon due to the large amounts of missions taken to study it
The moon like all other rocky bodies is made up of the same types of rocks as on earth
The moon is made up of mainly Anorthosite (The light highlands) and Basalt (The dark mares)
It also has a layer of lunar soil and breccia

Formation of the moon

4.5 billion years ago, a celestial body the size of Mars impacted Earth
The impact propelled material from the Earth and celestial body into space
After the impact, the rotation of the Earth sped up, and it tilted on its orbital plane
The Earth reformed from a molten body

The moon slowly aggregated from the debris left over

Journey to the centre of the Earth

The Earth in Numbers

The Earth's surface comprises 29.2% land and 70.8% water.
This equates to 149,000,000 km2 of land and 361,000,000 km2 of sea.
It has an equatorial circumference of 40,075km and an equatorial diameter of 12,756.3km.
It is around 4.6 billion years old or 4543 million years old.

The Anatomy of Earth

The Earth has four main structural layers: the crust, the mantle, the inner and outer core.
The Earth has internally differentiated into a layered structure: a solid metallic inner core, a liquid metallic outer core and a silicate mantle and crust.
Accretion of smaller meteorites under gravity
Heat of accretion causes rock to melt and mass increases strength of gravity.
Dense molten metals less buoyant sinks while lighter molten rocks are buoyant floats due to effects of gravity
The core of the earth is mostly mental the mantle and crust are metal depleted rock

How Do We Know This

We cannot make direct observations on this, however, so our knowledge is based on

- Direct Samples
- Geophysics
- Experiments
- The study of extraterrestrial materials

Direct Samples

We can study the inner structure of the Earth due to the existence of samples from the Earth's crust and mantle.
This is mostly done through xenoliths and core samples.
Xeno is the Greek word for foreigner or stranger, hence xenolith
Mantle xenoliths are parts of the mantle that are transferred to the Earth's surface due to magmatic processes, most of the time, this occurs as a section of peridotite encased in basalt
It can also be due to the mantles outcropping to the surface because of tectonic forces; this happens in large mountain ranges like the Alps or an area such as Macquarie ridge
Samples can also be found as small inclusions in diamond crystals that are brought up.
The most effective way to sample the crust is using a drill core, and these cores can reach up to 12km deep and show valuable information about the structure under the Earth.
We have no samples of the core of the Earth due to the immense amount of pressure and gravity there, meaning that no material can escape.

Geophysics

We can also tell what is below the surface of the Earth due to its physical properties, and these can include:

- Specific gravity
- Magnetism
- Seismology

Specific Gravity

Earth gravity (g) is the attractive force that the planet exerts on nearby objects or those on its surface
The apparent strength of Earth's gravity varies depending on changes in rock density
This can help in determining the structure of the crust and upper mantle

Magnetism

The Earth's magnetic field is tilted at 11° due to the axis on which the Earth spins.
Magnets lose their magnetism above 770 °C,
Considering the temperature gradient of Earth goes up to the thousands, there are either lots of magnetic materials around 25-30km from the surface or something else creates our magnetic field
Our magnetic field is preserved in surface rocks that contain traces of magnetic materials that will point north to south, this is called the paleomagnetic field.
Earth's magnetic field is similar to that caused by an electric current loop; this means there must be an electric current moving in a circular formation within the interior of the Earth
The most plausible way for this to occur would be a large volume of liquid metal
Our outer core is a liquid outer core of iron and nickel
This would also explain why the strength of the magnetic field varies across the planet

Seismology

Most of the information we know about the interior structure of the Earth comes from seismology (the study of waves created by earthquakes
There are three main types of earthquake wave
Primary waves or P-waves create a jolt by causing compression and dilation of rocks. They can travel through solids and liquids.
Secondary waves, or S-waves, these waves create a swaying movement up and down, shaking the ground in a vertical motion. These waves cannot travel through liquids or gasses.
Surface waves come in two types: Love and Rayleigh.
Seismic waves can be reflected off a boundary between rock layers of different densities within the deep Earth.
Seismographs at seismic monitoring stations can detect these reflected waves
The time the wave takes to travel can be used to work out the depth of the reflecting boundary
During an earthquake, the absence of S waves on seismographs created a shadow zone; this created the idea of a liquid layer in the Earth's interior
The refraction of P-Waves shows the boundary between the mantle and core due to a change in velocity
This can be used to estimate the size of the core

The study of extraterrestrial materials

Chondrites are stony meteorites that have the same composition as the average whole earth-earth formed from these, but the crust and mantle have less iron and nickel that chondrites

The Internal Structure of the Earth

The variations in seismic velocity, magnetism and composition allow us to categorize and divide the Earth into the crust, upper mantle, transition zone, lower mantle, outer and inner cores
The density variations that allow us to divide these layers are a result of:

- Changes in chemical composition
- Changes in mineral structures

The earth is divided into layers based on physical properties.

These divisions are able to represent the distinct, composition, density and strength of the material within the earth below
The chemical differences within these layers are also highly important
(Earth: An Introduction to Physical Geology)

The Furnace Below

The Earth's heat comes from two different sources; one of these is the original heat from the planet's accretion.
The other heat source is the decay of radioactive isotopes within the Earth's crust.
There is a gradient in this underground temperature because of conduction and convection.

The Crust

There are two different types of crust, oceanic and continental crust, and they make up 71% and 29%, respectively
There is an abundance of two major levels on Earth, the continental crust at around 1000m and the oceanic crust at about -4000m
Oceanic and continental crusts have different compositions

- Oceanic crust is made of mafic basalt, high in Mg and Fe
- Continental crust is made of felsic granite, high in Si and Al

The continental crust varies in thickness from 25 – 70km in size and is thickest around mountains.
It has a wide variety of compositions containing all igneous, sedimentary and metamorphic rocks.
It has a wide variety of ages.

The oceanic crust varies in thickness from 6 – 10km in size
It is mostly made of igneous basaltic rocks coated in a layer of sedimentary rocks from the seabed
The oldest oceanic crust is 200 Ma, as anything older than that will be subducted and destroyed

Oceanic crust is:
It is 7-10km thick
It is made of mafic rocks
It is dense and heavy
Density=2,9g/cm3
dark colour, high is magnesium iron and silicon
Continental crust is:
t is 30-40km thick
It is made of Felsic rocks
It is thin and light
Density=2.7g/
light colour, high in aluminium and silicon

There are two main types of crust: oceanic and continental
The earth's crust is very thick in comparison with the rest of the earth, being about 7km thick for oceanic crust and 35-70km in continental crust.
Oceanic crust is composed of thick dark mafic rocks, the continental crust consists of many different types of rocks.
The average composition of the continental crust Is granodiorite
Continental rocks have a density of around 2.7g/cm^3, the oceanic crust has a density of around 3 g/cm^3.
Some of the oldest continental rocks are around 4 billion years old, while the oceanic crust can only reach around 180million years old before it Is subducted
(Earth: An Introduction to Physical Geology)

The mantle

The mantle is made of peridotite, which is composed of olivine
This has been determined through seismic velocities and xenoliths
There are various layers of the mantle, essentially a giant marble cake
The lithosphere, which is a rigid section of the mantle on the base of the tectonic plates
The asthenosphere, which is a section of the mantle with plastic rocks (solid with 1% magma)
The upper mantle is 670km deep and the lower mantle goes down to 2900km deep.

The mantle is made of ultramafic rocks and is a plastic state
The mantle is 2900km – 100km
High density and high in iron magnesium silicon and oxygen
The upper mantle is made of ultramafic rocks called peridotite across
The mantle is solid but plastic able to deform like plasticine.
Heat from the outer core heat up the mantle.
This heating causes the mantle to convict like a boiling pot of rice due to differences on density.
The current formed from this drive plate tectonics and influence the crust.

More than 82% of earths volume is contained within the mantle.
The mantle is a solid rocky shell that is 2900km thick
The boundary between the crust and the mantle is shown as a change in the composition between the peridotite rich mantle and the continental and oceanic crust
The upper mantle extends from the crust boundary to around 660km in depth
It can be subdivided into 3 main sections; the lithosphere, the asthenosphere and the transition zone.
The lithosphere is the entire crust as well as the uppermost mantle, and it forms the earths solid cool outer shell
The lithosphere is around 100km thick and can reach up to 250km thick beneath the oldest sections of the crust
The asthenosphere extends from the base of this layer to around 410km in depth
The top of the asthenosphere has temperatures and pressures that allow for a small amount of melting, mechanical detaching the lithosphere from the layers below allowing it to move independently.
The rocks of the lithosphere behave differently to those in the surface, due to the temperatures that they are under the rocks are close to their melting points so can be easily deformed.
From 410km to 660km the transition zone marks the increase of the density of rocks from 3.5 to 3.7
This change occurs due to the peridotite forming new denser structures and different minerals due to the pressure and temperature
The lower mantle extends from a depth of 660km to the top of the earth's core at around 2900km.
Because of the gradual increase in pressure caused by the weight of the rocks above it the rocks in the lower mantle gets stronger the deeper you go.
The mantle also becomes capable of gradual flow
In the very bottom layer of the mantle there is a layer called the D" layer (D double prime layer).

(Earth: An Introduction to Physical Geology)

The Core

We have no direct samples of the Earth's core due to the pressure and gravity (stated above ^)
The best example is iron meteorites, fragmented parts of planet cores.
They are made up of Iron and Nickle, with trace amounts of cobalt
They exhibit Widmanstätten patterns, meaning separate formations of iron and nickel
The outer core is molten, which creates the magnetic field (stated above ^)
The inner core is solid and is slowly growing as the core cools down
The inner core is the size of the moon with a radius of 1220km radius
The core spins faster than the surface of the Earth

The temperature estimates are around 4500 and 6000 °C
Our core is mostly made of Fe + Ni, and it also contains sulphur and siderophile elements
Without our core, we would have no magnetic field, meaning that solar wind and flares would evaporate the atmosphere and oceans

The inner core is solid and made of Fe and Ni.
It stretches from 6378 – 5100km below the earth
It has the highest density and the highest temperature
The outer core is liquid and made up of Fe, Ni, and small amounts of S
It goes from 5100km – 2900km.

The core of the earth is composed of an iron nickel alloy along with other siderophile elements such as oxygen, silicon and sulphur.
Due to the immense amounts of pressure the core is under the density of the material in the core is around 11 g/cm^3, and around the centre of the earth has a density of around 14 g/cm^3.
They can be subdivided into two regions with different properties, the inner and outer core.
The outer core is a liquid layer that is 2250km thick.
The movement of this liquid iron layer creates the earth's magnetic field
The inner core is a sphere about the size of the moon with a radius of 1221km.
It is under such a high amount of pressure that despite the high temperatures the inner core remains solid.

(Earth: An Introduction to Physical Geology)

The Dance of the Plates

What are tectonic plates?

Plates tectonics is the drifting fragments of the lithosphere
The lithosphere is the crust and the top of the mantle
They drift on the asthenosphere due to the convention of the mantle
They move around 10cm a year

Tectonic plates are large sections of the Earth's crust, which is the outermost layer of the planet. These plates, ranging in size from a few kilometres to thousands of kilometres across, fit together like a jigsaw puzzle and float on the semi-fluid mantle beneath them. The movement of these plates is responsible for various geological phenomena, including earthquakes, volcanoes, mountain formation, and the shaping of continents over millions of years.

Features of the Oceanic Plates

The oceanic plates have various features, each with different geology and characteristics

- The abyssal plains
- The mid-ocean ridges
- Seamounts
- Island arcs
- Oceanic trenches

The Abyssal Plains

Most of the ocean is dominated by flat areas known as the abyssal plains.
They are around 4-5km deep
They are composed of basalt with a thin layer of sedimentary rocks
They have no magmatism
There is life present, but it is scarce

Mid Ocean Ridges

Long the underwater plate boundaries, there are elongated ridges
These make up the Mid Ocean Ridges (MORs)
They rise above the ocean floor
In Iceland, they rise above the sea level
They are around 2.5km below sea level
They are responsible for the production of basaltic magma at the plate boundaries.
They have transformed faults as well, which occur as a linear feature
These transform faults help to allow curves in the tectonic plates
They contain many hot springs and hydrothermal vents supporting active and lively ecosystems
Hydrothermal vents are fissures where mineral-rich geothermally heated water is ejected out.
The mid ocean ridge it the world's longest mountain range, though it is entirely underwater.
It was discovered when the USA started mapping the sea floor using sonar and submarines.

Seamounts

Isolated mountains on the sea floor are called seamounts
Some are part of volcanic island chains
When a seamount rises above sea level, it is called a volcanic island
They are not indicators of plate boundaries
They allow geologists to understand the mantle magmatic processes

Island Arcs

A chain of islands bound by an oceanic trench is called an island arc
These island arcs show extensive volcanism from composite to shield volcanoes
They are also areas of significant seismic activity

Deep Ocean Trenches

Deep ocean trenches are deep, narrow depressions on the ocean floor.
They are the deepest points on the surface of the Earth.
Challenger deep is 10,850m below sea level.
They form due to the subduction of an oceanic plate
They can be up to 2400km long and 100km wide
Only five ocean trenches are deeper than 10km
The water pressure that far down is around 1000 times the atmosphere at the surface
It accumulates carbon through sediment.

The continents

Like the oceans, the continents are mainly flat plains
Mountain ranges from high ridges across the surface
Most magmatic and seismic activity is located in these high areas
The flat areas are mainly quiet

Australia In Focus

Australia is predominantly a large, flat, plain
We have a mountain range (the great dividing ranges)
The highest point in the country is Mt Kosciuszko
Australia's geology is mainly composed of:

- Cratons
- Basins

- Mobile Belts
- And Phanerozoic Cover

A craton is an area dominated by igneous and metamorphic rocks older than 2.5 Ga
A basin is a depression filled with sediments – like me
A mobile belt is the root of an old mountain chain that experiences deformation and high-grade metamorphism during continental collisions
Phanerozoic cover is a recent cover of sediments and volcanic rocks

Continental To Oceanic Boundaries

Two main types of boundaries can be identified along these boundaries
Passive continental margins or active continental margins
The difference between the two is the amount of active volcanism or seismic activity

Continental Drift

The hypothesis of continental drift was first proposed by meteorologist Alfred Wegner in 1912
His hypothesis was not initially accepted as the scientific community instead believed that the continents and oceans were permanent features
His hypothesis was based on several key points of evidence:

- Coastal fit
- Geology
- Biology
- Paleoclimate

His hypothesis was proved correct through discoveries on plate tectonics. Modern evidence to back his claim up can be found in:

- Magnetism
- Plate Speed

Continental drift is the horizontal movement of the continents due to seafloor spreading and convection
It was first proposed by the German scientist Alfred Wegner when he found evidence that the continence must have at some point been connected.
He had lots of evidence to show that they had moved but not on how they had moved so his theory was rejected
Before Alfred Wegener geologists considered the continents and oceans as being in a fixed position for all time.
Wegener proposed that all of the continents were once all connected together as part of a giant supercontinent, he called Pangaea
This was named after the Greek for all land, Pan = All, Gaia = The primordial of the earth
He proposed that this supercontinent existed at the end of the Palaeozoic Era and would have broken apart somehow in the Mesozoic causing the formation of the continents that look similar to today
(*Earth: A Portrait of a Planet)*

Coastal Fit

One of the most supportive pieces of evidence for continental drift is that all continents fit together to form one supercontinent.
This suggests that once great supercontinents fit together in the Earth's past.
One of the most obvious pieces of evidence is that the continents fit together in a big jigsaw.
One of the most obvious fits is Africa and south America, this if including the continental shelves currently underwater.

Wegner assembled all of the continents together and makes the supercontinent know as Pangea
Pangea means all of earth

When explorers where first mapping coastlines scholars who studied these maps noticed that the continents seemed to fit together.
These fits were very prominent across the globe and could fit together all of the continents
Wegener concluded that this precise fit of the continents was too great of a coincidence and so they must have been connected to each other at one point in time
(*Earth: A Portrait of a Planet)*

Geology

A large number of geological features formed at the same time can be linked across the Earth.
A good example is mobile belts and cratons (stated above ^)
This means that the continents that fit together also had the same geology spanning across them

Biology

Biological evidence for continental drift can be found in palaeontology or by tracing genetic ancestors between separate species to a common ancestor.

In the early 1900's Wegner noticed that the South America, Africa, India, Antarctica, and Australia have almost identical late Paleozoic rocks and fossils
This provides more evidence for the continent fitting together as there would have been no way for these creatures to cross oceans or swim
Some examples include

- Glossopteris (plant), Lystrosaurus and Cynognathus (animals) fossils found on all five continents
- Mesosaurus (reptile) fossils found in Brazil and South Africa only

Paleoclimate

The distribution of glacial deposits across the southern hemisphere shows that the continents were once in different locations and joined together.
Striated rocks can mark Paleo ice caps
Paleo tropics and deserts can also be identified via geological records

Paleoclimate is the past climate of an area.
The proof of paleoclimate can be seen in the country's that made up Gondwanaland.
They all share glaciation patterns
Coal beds of North America and Europe support reconstruction into Laurasia.
Reconstructed paleoclimate belts indicate land masses positions relative to the Earth's poles which provides potential evidence for continental drift over time

Magnetism

Magnetic minerals within a magma or lava will align with the Earth's magnetic field
Once they have cooled and crystalized, the magnetic data is locked into place
Over time, the Earth's magnetic field shifts and reverses
This magma formed at the MORs (Mid Ocean Ridges) aligns with the magnetic field, preserving it at the time of formation
As the plates shift in location, new rocks will create parallel magnetic banding of normal and reversed polarity moving away from the ridges
This means that new oceanic crust pushes old oceanic crust away from ridges, shifting the tectonic plates (See Ridge Push)

This can help track the original location of the plates as if the minerals are facing east-west, we can tell that they have been slowly turned over time

This allows us to tell the age of the crust, the oldest being 220Ma

Paleomagnetism is the rocks magnetic direction at the time of its formation
Rocks with increasing age point to magnetic pole locations increasingly far from today's
Marine magnetic bands are bands of normal and reverse polarity of magnetic minerals.
Parallel mid-oceanic ridges
Field strength related to basalts magnetized with same and opposite polarities of current global magnetic field
Symmetric bar-code anomaly pattern reflects plate motion away from ridge coupled with magnetic field reversals

Plate Speed

This is a more modern piece of evidence, but we can now directly use GPS and lasers to measure the exact movement of plates along faults.
This has shown us that they move only several centimetres a year.

Plate Tectonics

plate tectonics is the fact that Earth's surface is divided into a few large, thick plates that move slowly and change in size and shape.
Intense geologic activity is concentrated at plate boundaries, where plates move away, toward or past each other
Theory born in late 1960s by combining hypotheses of continental drift and seafloor spreading
The crust is broken into a series of continental and oceanic plates.
These plates move slowly over time due to the creation and destruction of oceanic crust.
Continental crust is too buoyant to be destroyed and therefore remains at the surface, being pushed around by moving oceanic crust.
The process is driven by the thermal convection of the mantle, and results in many of the large-scale geological processes we witness today.
Plate tectonics is the theory that provides a view of the processes that produced the continents and oceans, using this theory geologists can find explanations for the formation of geological features, the occurrence of natural hazards and arrangements of the continents
(Earth: An Introduction to Physical Geology)

Seafloor Spreading

In 1962, Harry Hess proposed seafloor spreading.
Supporting evidence for the theory includes:

- The discovery of mid ocean ridges.
- Paleomagnetic striping on the sea floor.
- Sea floor (radiometric) age dating.

At mid ocean ridges, upwelling convection currents from the mantle push the crust apart and form new basaltic oceanic crust.
Seafloor rocks, and mantle rocks beneath them, cool and become denser with distance from mid-oceanic ridge
When sufficiently cool and dense, these rocks may sink back into the mantle at subduction zones.
Seafloor age increases with distance from mid-oceanic ridge, indicating new material is continuously being created there.
Basically, no oceanic crust older than ~200 Ma, and must therefore also be being destroyed.

Tectonic Plate boundaries

Most of the tectonic boundaries can be traced out via the occurrence of earthquakes
This is also consistent with most volcanic activity

The Ring of Fire is a famous active boundary that surrounds the Pacific plate
There are few earthquakes and no active volcanoes in Australia due to its position in the centre of its plate
There are three main types of boundaries

- Convergent boundaries, a plate goes below another
- Divergent boundaries: a plate goes away from another
- Transform boundaries, slide past each other

Divergent boundaries

Divergent boundaries occur along MORs or rift valleys on continents
They have sustained basaltic volcanism as they are constantly creating new crust
Along the oceans, the MORs create new oceanic crust
On land, rift valleys also create new crust but a lot slower.
The Great Rift Valley in Africa is the best example of this.
Divergent boundaries occur where tectonic plates move away from each other. This movement results in the upwelling of material from the mantle, creating new crust and widening the gap between the plates. As a result, ridges and rift valleys are formed. These regions are characterized by volcanic activity and frequent earthquakes. One prominent example of a divergent boundary is the Mid-Atlantic Ridge.

Convergent Boundaries

Convergent Boundaries occur between oceanic-to-oceanic crust, oceanic-to-continental crust and continental-to-continental crust
They are characterized by their compression of the crust and tectonic features of magmatic arcs and deep earthquakes.
They destroy the oceanic crust by forcing it down into subduction zones
Convergent boundaries may eventually result in the collision of continents
Continental to continental changes create mountains- they as big on top as bottom (Isostasy)
Convergent boundaries are formed when two tectonic plates move towards each other. As they collide, one plate is usually forced underneath the other in a process called subduction. This collision leads to the subduction of old crust and the formation of deep ocean trenches, volcanic arcs, and mountain ranges. The Pacific Ring of Fire is a well-known area with numerous convergent boundaries, resulting in frequent seismic and volcanic activity.

Transform boundaries

Transform boundaries are plates that slide past each other
This creates no magmatism.
There can be leaks in the fault that allow magma through, but there is no magmatism.
They create massive fault earthquakes.
Transform boundaries are formed when tectonic plates slide past each other horizontally. The plates do not converge or diverge but instead grind against one another. The movement at these boundaries is often jerky and results in frequent earthquakes. One of the most famous transform boundaries is the San Andreas fault in California, where the Pacific Plate and the North American Plate slide past each other.

Intra Plate Magmatism

Magmatic activity at seamounts or volcanic islands is not at plate boundaries.
They take place at local hot spots on plates
This happens as the mantle has conventions like a lava lamp
Mantle plumes are circular upwellings of magma from the mantle that go up to the surface

Volcanic islands and seamounts are created as the plate passes over the stationary hot spot, creating a chain of volcanoes that get older away from the hot spot. (Creates evidence for continental drift)

Drivers of Plate Tectonics

Ridge Push

- As magma rises to the surface and solidifies, it creates new lithosphere, pushing the existing plates apart.
- The newly formed lithosphere is warm and buoyant, giving it gravitational potential energy. It pushes downward and outward from the ridge exerting a horizontal force that pushes the adjacent plates apart.
- This process contributes to the spreading of the seafloor and the widening of ocean basins.

Mantle Drag

- The asthenosphere, a weak and viscous region in the upper mantle, is able to shear and deform under pressure.
- As the rigid lithospheric plates move over the asthenosphere, they experience resistance and drag as the aesthenosphere slowly deforms.
- This drag force acts to slow down the plates and influence their motion.
- The asthenosphere's flow patterns can be influenced by convection currents, which further affect the movement of the overlying plates.

Slab Pull

- Oceanic plates at subduction zones are more dense than continental plates and therefore descends into the mantle due to gravity.
- As they do, they pull the rest of the plate along with it.
- The sinking plate, known as the slab, experiences a gravitational pull that creates a dragging force on the rest of the plate.
- This force contributes significantly to the overall motion of the plates and is a key driver of plate tectonics.

Time Travel Through Earths History

How old is the earth?

Until relatively recently, people in most cultures believed that geologic time began about the same time that human history began and that the Earth has been unchanged since its humanities birth. This age differed from culture to culture.
An Irish archbishop named James Ussher tallied successions of lineages and reigns described in the Old and New Testaments to determine the age of the Earth and, in 1654, stated the birth Of the Earth took place on October 23, 4004 B.C.E. He was very wrong

Other beliefs and religions such as Chinese and Hindu beliefs, the Earth was thought to be unexplainably old, up to trillions of years.

This idea of the unchanging earth was disputed when around 1650 Nicolas Steno, a nobleman's physician theorised that the occurrence of fossils found throughout the hills in the Florence area must mean they were buried along with the sediment before being lifted out of the sea when the mountains formed.
He concluded that the presence of the shark teeth along with other marine fossils meant that the world changed over time.
This realisation helped create the basis for the founding of Geology by James Hutton

(Earth: A Portrait of a Planet)

James Hutton's Theory

Hutton was a Scottish farmer and doctor who lived in the Age of Enlightenment.
This was a time when due to the discovery of the laws of physics by Sir Isaac Newton scientists began to seek natural rather than supernatural explanations for the world around them.
While wandering among rock outcrops in the highlands of Scotland, Hutton noted that a majority of the features found in sedimentary rocks could also be found in sedimentary basins around him.
These observations led Hutton to propose that the rocks and landscapes, were a consequence of processes that he could see happening today.
Hutton's idea, was published in 1785 in his book called The Theory of the Earth, came to be known as the principle of uniformitarianism.
According to this principle, physical processes we observe today also operated in the past at roughly the same rates, and these processes were responsible for the formation of geologic features that we now see in outcrops.
To simplify ,the principle states "the present is the key to the past."
Because the rates of most geologic processes taking place today are so slow, Hutton deduced that the development of individual geologic features takes a very long time.
Further, he figured out that not all features formed at the same time, so the Earth must have a history that includes a succession of slow events, and therefore, the Earth existed for a long time before human history began.
(*Earth: A Portrait of a Planet)*

The birth of the Earth – 4.53 Ga

Earth is only 1/3 of the age of the universe
Earth took 40 million years to form the accretion of meteorites and planetary material.
The impacts during this accretion created the heat to melt the rocks and round out the planet.
"Asteroid natural selection" – the larger the body the more successful
Due to the melting of the planet, the layers of the Earth differentiated, metals sank to form the core, partial melts rose to form a proto-crust, and gas escaped to the proto-atmosphere
As the Earth accreted from the planetary nebula, it trapped gasses.
These gasses were largely hydrogen, helium, methane, water and minor traces of other gasses.
The solar wind bearing down on the earth at this time would have "photoevaporated" the lighter gasses like hydrogen and helium, who reach escape velocity more easily.
At the very high heat all water evaporates and the earth is molten

Formation of the moon – 4.43 Ga

The moon was formed between the impacts of the proto-earth (90% mass relative to today) and a Mars-sized body named Theia.
This impact caused the temperatures to rise dramatically, up 10,000°C
This caused the ejection of lots of material, creating rings around the Earth for a while
Eventually, the rings accreted into the moon
Our moon is large compared to our planets
This new moon helped to stabilize the Earth on its axis, leading to stable climates.
We don't get rings they stabilise into moons =(

Formation of the oceans and atmosphere – 4.43 Ga

At the formation of the Earth, the early atmosphere consisted of water vapour, Carbon Dioxide, Nitrogen and methane.
When the Earth had cooled enough, the water vapour in the air started to condense.
{Owens Notes: This period it rained nonstop for 10,000 years}

We know of this due to a 4.4-billion-year-old zircon with signs of water alteration
The hydrological cycle starts (The Water Cycle)
Carbon Dioxide becomes trapped in the water and then in the sediments that become part of the crust or mantle, which cools the planet more.
This meant nitrogen was now the dominant gas in the atmosphere
At this point, the surface looked very different as iron in the ocean meant it was green, the greenhouse gasses (methane) in the atmosphere made it red (same way oxygen makes blue), and the continents were mainly black basalt

We can measure the amount of water on earth and the isotope ration of heavy water v light water.
There are not enough sources of light water for amount of light water we have.
Some of the light water is formed by solar radiation on asteroids

In the Hadean period hydrogen and Helium are rapidly leaving the atmosphere as they "photoevaporated".

(Hadean, Origins is in the Greek Hades: God of the underworld and dead, the planet reflecting that)

The remaining atmosphere is heavy and rich in CO_2, H_2O and NH_3, early oceans formed under high pressure.
CO_2 decreased as it dissolved in oceans and was removed by subduction into mantle.
Formed the core of the earth
The late heavy bombardment adds water
As earth cooled, water condensed (H_2O removed from atmosphere) and formed oceans.
Earth is the only planet in the solar system that has water occurring it it's surface in all three phases – solid, liquid and gas.
As far as we know, liquid water is essential for life.
When the earth first formed, it was very hot, with a molten surface. Conditions were initially too hot to from liquid water.
After around 500 million years, it had cooled enough for the water in the atmosphere to condense.
Over thousands of years, this condensing water filled the oceans.
Earth's oceans are thought to be about 3.9 billion years old.
There are two hypotheses about how Earth got its water.

Volcanic outgassing

- volcanoes vent gasses including water to the earth's surface
- the veterinary water hypothesis says that trapped water from earths formation was retinas to the surface in earth early history by volcanic outgassing
- this process continues at a slower rate today and water is

Planetary accretion

- Earth formed from a planetary nebula of dust and rocks.
- Many of these particles contained water in the form of an ice coating on dust grains.
- When these formed together to create earth, much of the water was trapped inside the planet
- Volcanoes vent gasses, including water, to the earth's surface.
- The accretionary water hypothesis says that trapped water from Earth's formation was returned to the surface in earth's early history by volcanic outgassing.
- This process continues at a slower rate today, and water is a common gas from nearly all volcanoes.
- New studies have found evidence that the mantle transition zone (250 km thick) may contain as much water as Earth's total oceans.
- This water is trapped inside mineral crystals, which may be between 1 and 2% water.

The solar system contains many icy bodies called comets.
These comets sometimes visible from Earth are left over from the early solar system.
The early solar system had many more comets than today.
Earlier in the solar system's history, there were more bodies, including comets, orbiting around the solar system.
Over time, the gravity of the planets sucked them up, and collected water and other gasses in the process.

The Oldest Mineral on Earth – 4.37 Ga

The oldest Mineral on Earth is a Zircon crystal that was dated to around 4.375 Ga
It was found in WA and dated by Curtin University.
Its chemical composition suggests they come from water-rich granite-like rocks.
This means surface water was present at this time.

The Oldest Rock on Earth - 4.03 Ga

An Acasta Gneiss formation in Canada has been dated at 4.031 Ga
Before its metamorphism, the gneiss was a granite rock
This shows that granites are similar today to 4 billion years ago
This shows that a form of plate tectonics was present 4 billion years ago
Water entering the mantle of the Earth because of sinking basalt is the key to producing these granites

The creation of BIF – 3.7 Ga

Banded Iron Formations (BIFs) are a rock formation that is enriched with bands of iron oxides such as magnetite's or hematite and alternating with silica (chert) layers
They are formed when:

- Iron produced by a MOR is dissolved in anoxic water
- The iron is oxidized by interaction with oxygen from cyanobacteria, forming oxides
- The oxides precipitate to the ocean floor on top of a layer of iron-poor silicates
- The buried sediments turn to rocks through diagenesis

Cloud (1973) explained BIF as evidence of photosynthesis carried out by cyanobacteria.
The oxygen by product combined with dissolved iron ions (Fe^{2+}) to from the iron oxides (Fe_2O_2,Fe_3O_4) in iron rich bands
Local accumulations of oxygen would kill of cyanobacteria leading to deposition of iron poor bands
cyanobacteria form O_2 from Fe oxide
iron is depleted O_2 accumulations
O_2 toxic to CB, CB die off
chert is deposited
Fe is refreshed, CB recovers repeats
CB from O_2 forms Fe oxides
Fe is depleted chert is deposited instead
upwelling deep ocean water refreshed ion
cycle repeats
The evolution of oxygen photosynthesis totally changed earths spheres
The geosphere gained vats BIFs.
The hydrosphere becomes depleted in iron.
Large amount of carbon moved into the biosphere decreasing carbon dioxides in the hydrosphere and atmosphere.
After 2 billion years of BIFs, oxygen began to accumulate in the hydrosphere and atmosphere.

The first Evidence for life – 3.5Ga

Stromatolites are the oldest and first irrefutable proof of early life
The oldest stromatolite is 3.5 GA and is found near Marble Bar in the Pilbara
This makes stromatolites one of the most successful organisms of all time
Stromatolites are created by bacteria when they use sticky glue to trap layers of sediment.
Water circulates through and around this, hardening the structure.

The first photosynthesis - 2.8-3.4 Ga

Cyanobacteria were the first photosynthetic life.
Photosynthesis is when light is used to assemble glucose from carbon dioxide and water.
This created oxygen as a byproduct, which accumulated in the atmosphere
Oxygen is toxic and the biggest environmental destroyer of all time
The oxygen accumulation was slow until the great oxidization event
oxygen photosynthesis is very efficient at least 10x more than other types.
inputs of carbon dioxide and water are abundant.
oxygen was toxic to most microbes.
this led to the first mass extinction.
oxygen was toxic to most microbes this led to the first mass extinction.

The great oxidization event - 2.4-2.5 Ga

The great oxidization event was the rapid rise in the level of oxygen in the atmosphere and ocean.
It killed off many anaerobic bacteria, causing one of the first mass extinctions.
We have evidence for it in the change of sulphur isotopes and the types of stable minerals.
This rise in oxygen created the energy for aerobic life and caused the diversification and evolutionary leap.
Photosynthesizing life forms (cyanobacteria) evolved ~2.4 billion years ago. They started reducing the amount of CO_2 in the atmosphere.
$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$
Carbon Dioxide + water → Glucose + Oxygen
This period is known as the great oxidation event, and it changed the planet entirely.
As oxygen was produced, it was initially consumed by dissolved iron in the ocean, forming iron oxides.
Therefore, Atmospheric oxygen DID NOT RISE immediately with the advent of photosynthesis
Iron in the oceans consumed the oxygen and acted as an oxygen sink.
Banded Iron Formation is a rock composed largely of iron oxides which occurs all over the world. It all formed between 2.4 and 1.9 billion years ago, starting with the evolution of photosynthetic cyanobacteria, which formed stromatolites.
The availability of free oxygen in the atmosphere allowed for the formation of the ozone layer by around 600Ma.
This allowed the formation of more complex life as single cells cope better with damage than multicellular organisms and life that could leave the protection of the ocean and colonise the land.

The first Snowball Earth - 2.3-2.2 Ga

The snowball Earth happened when almost all of Earth was covered by glaciers.
The average temperature dropped to around -40
It was initially caused by a climate shift that increased the ice on the Earth's surface.
This higher amount of surface ice gave the Earth higher albedo, causing temperature drops, which caused more ice to form.
This event created evidence of glacial deposits in equatorial regions; these include striated rocks and dropstones.

This period ended due to a volcanic eruption that increased greenhouse gasses in the atmosphere.

The formation of Nuna - 1.8-1.4 Ga

Around 2.1-1.8 Ga, all of the major cratons are assembled
There is evidence for this collision based on palaeomagnetism, the roots of mountain changes and volcanic provinces
It made up a single continent that was stable for 400 Ma
It has a stable, warm climate
The collision boundaries of this supercontinent relate to mineral deposits (see below \/)

Rodinia and snowball Earth II - 2.5 Ga – 541 Ma

Rodinia assembled around 1.3 to 0.9 Ga and broke up around 0.75 Ga
There were also 2 More snowball Earth events during this period, around 720 -660 Ma and 650-635 Ma

The Cryogenian Period 720-635 Ma

The Cryogenian Period (720-635 Ma) is inferred from globalised evidence of glaciation, indicating that the planet experienced a significant global ice age.
This period ended with a warming phase, resulting in:
Vast melting of ice sheets,
Nutrient rich meltwater to oceans, therefore there was a boom of cyanobacteria.

The Ediacaran fauna and the rise of complex life - 575 – 542 Ma

The Ediacaran fauna are soft-bodied organisms that left preserved traces in late Proterozoic rocks
There are 31 species
They only survived for a short period
Most of them are metazoan
They are named after the Ediacara hills in South Australia, where they were discovered.

The “Ediacaran” fauna lived during the Ediacaran period (635 – 542 Ma)
This period in time is named after the Ediacaran Hills region of the Flinders Ranges, in which many of the fossil remains have been found.
They represent the earliest evidence of multicellular life
The Ediacaran fauna were all soft bodied (no teeth or bones) and therefore did not fossilise well.
Their fossil remains occur in the form of burrows or imprints in sediments
Ediacaran fauna likely radiated in a response to the high oxygen and organic material created by CB following the end of the Cryogenian.
Likely the first metazoans (had differentiated tissues)
Many were sessile (not moving) benthic (sea floor) organisms.
Had simple respiratory systems as they didn’t need complicated organs to do this
Ediacaran fauna only formed trace fossils as they didn’t have solid body structures

The Cambrian explosion – 541 Ma

The Cambrian explosion was the rapid appearance and diversification of most phyla.
It is the emergence of modern life
The rise of predation in this period wiped out the Ediacaran fauna
It created a diversity of animals
An increase in oxygen caused this

The Cambrian Explosion occurred around 541 Ma and resulted in the proliferation and massive radiation of multicellular life.

All sorts of amazing life forms formed during this time, which for a long time (continuing today) have baffled scientists.
Ediacaran Fauna went extinct at this time, perhaps they were:

- Out competed primitive respiratory systems and body plans put them at a disadvantage and they suffocated
- Preyed upon lacking any hard parts, they would have been very easy pickings for the Cambrian species that followed.

The Permian-Triassic extinction – 252 Ma

This extinction event killed over 95% of marine and 70% of terrestrial species.
It lasted a few hundred thousand years.
It is also called the Great Dying
It set the stage for the archosaurs and dinosaurs
Trilobites are gone =(
It was caused by the eruption of the Siberian traps, which created shifts in temperature and environmental conditions.

Impact of a meteorite

Shack quartz has been found in global sediments.
Suddenness would explain why organisms did not evolve to cope with change
May have caused subsequent volcanism which causes all bad things
The opening of the Siberian traps large basalt floodplain which covered two million square kilometres of earth surface
This would have caused caid rain and duct clouds
Methane is 40 times stronger a greenhouse gas than CO_2
Releasing a lot of methane from Siberian permafrost would have rapidly accelerated.
The reduction of oxygen in the ocean due to warmer temperatures allowed surface reducing bacteria to flourish
A collection of all of the above perhaps except a meteorite impact through this may have been the trigger to the volcanism
The Siberian traps open
Tons of CO_2 is released from them, coal deposits are ignited, forests burn.
Ash and acid rain kill plant life and marine ecosystem
This heating shutdown the thermohaline circulation, this causes anoxic oceans.
Methane and hydrogen sulphides if formed in the ocean.
Everything dies (70% of all life and 90% of all marine life)
It is also called the Great dying

Pangea Supercontinent 335-175 Ma

The supercontinent Pangea was centred on the equator and surrounded by the ocean Panthalassa and the Tethys Sea.
Most of the landmass was dry as mountain chains blocked the moisture from the oceans.
Average temperatures were around 20°C
Pangea ended with the mass extinction and eventually broke into Laurasia and Gondwana.
Its breakup is still happening in the African Rift Valley.

Dinosaurs - 230-66 Ma

Dinosaurs are the most successful animal group on Earth time-wise, having existed for 165 million years.
Contrary to popular media, many dinosaurs had feathers
Modern birds are descended from them
They laid eggs

Different dinosaurs lived at vastly different times

The extinction of the dinosaurs – 66 Ma

The extinction of the dinosaurs creates a boundary between the Cretaceous and the Paleogene.
All of the non-avian dinosaurs went extinct.
At the boundary, there is evidence of a large impact in shock quartz, tektites, and a layer of iridium.
There is also evidence of large volcanic activity in the Deccan traps, like the Permian-Triassic and the Triassic-Jurassic boundaries.
The large impact likely caused the volcanism due to the impact forces.

The end-Cretaceous mass extinction is the smallest, but most recent, of the big five extinctions.
Hence, it is the best studied of the mass extinctions and the best understood.
It is commonly referred to as the 'K/ T event' or the 'Cretaceous—Tertiary boundary extinction'.
Because it happened recently there are many well-preserved, well-exposed and easily studied sequences of terrestrial and marine sedimentary rocks that span the period of time during which it occurred.
The K-T boundary is the boundary between the Cretaceous and the Tertiary layers of rock.
It also shows evidence for the Cretaceous mass extinction
Bolide – A meteor that hits the ground
It hits the Yucatan peninsula around 66 million years ago
It was around 10 km tall
Evidence For the bolide impact theory
The evidence for a bolide impact right at the Cretaceous—Tertiary boundary is over- whelming and includes the following three pieces of information as well as others.

<u>The Impact crater</u>

There is a large impact crater located beneath the Yucatan Peninsula, which juts out into the Gulf of Mexico, that is consistent with the impact of a comet or asteroid about 10 km in diameter. This is the so-called Chicxulub Crater and it has been dated to be 65 Ma old, precisely the age of the K/T event.

<u>The boundary layer</u>

A special layer of clay that can be found at many sites around the world separates the older Cretaceous rocks from the younger Tertiary rocks.
This clay is generally green in colour and is known as the boundary layer because it occurs right on the Cretaceous—Tertiary boundary.
The clay contains two very unusual features that are typically associated with bolides and their impact craters, providing strong evidence for the bolide impact theory.
First, it contains a variety of quartz that only forms at extremely high pressure and is only naturally formed in meteorite impact craters.
The quartz also usually displays fractures that are characteristic of impact shock.
This is why it is called ‘shock-quartz’
The second feature associated with the boundary clay is unusually high concentrations of the element iridium.
Such high levels of iridium are typically found in meteorites, comets and asteroids.
There is also evidence of ejecta, pieces of rock thrown out of the ground by an impact.
When it hit the asteroid would have caused;
The impact of the asteroid would have initially caused high temperatures from impacts
Tsunamis
Earthquakes
Volcanoes
Re-entry of ejector or meteorites
Wild fires
Long term impacts

Ash and aerosols
Blocking out the sun
Stopping of photosynthesis
Global ice age
Ash and aerosol coat the atmosphere and block out the sun
This kills plants that undergo photosynthesis
Global temperatures go from high to very low causing a global ice age

The rise of the mammals & humans – 5 Ma

Evolution led to the emergence of the homo sapiens within the hominid family.
Humans separated from chimpanzees around 5-7 million years ago
Hominids evolved in Africa and migrated outwards around 2 million years ago
The modern human appeared around 250,000 years ago
There are currently 8.2 billion humans on Earth, and altogether, we have planetary-scale impacts on the planet in all of the four spheres.
We are now 0.727 on the Kardashev scale showing the control we have over the different spheres of our planet

The Geological Time Scale

To develop a time scale applicable to the whole Earth, rocks of similar age but from different regions are matched up.

Earth Processes

The Rock Cycle

The Rock Cycle helps us understand how the 3 main types of rocks were created and the processes that interlink them
The rock cycle is the process of rocks transforming from one type of rock to another through processes such as melting and erosion

What is a rock

A rock is a bound aggregate of minerals
Granite consists of; Quartz, feldspar, hornblende,
Minerals are naturally occurring inorganic crystalline solids with an orderly repeating internal structure
Rocks tell us about the past earth and understand how other worlds formed and function
Rocks are naturally occurring aggregates of one or more minerals.
Rocks are classified on their origin
This is either Igneous, Sedimentary, or metamorphic
Igneous rocks are rocks that form from the cooling of molten minerals in lava or magma
Sedimentary rocks are rocks that are made up of compacted and cemented sediments
Metamorphic rocks are rocks that have had their form changed by heat and/or pressure
Most rocks are made up of a mixture of different solid partials, these are called minerals
Each mineral type has a specific chemical composition and special physical properties.

How can a rock shape our planet

The oceanic plates absorb water
These plates then subduct
The oceanic plate adds water to the solid mantle

This water helps solid mantle to melt and rise to the surface
The gas with the magma rises up and ash and basaltic rocks erupt creating tall stratovolcanoes
A new volcanic mountain chain is created
This mountain chain then effects the climate and environment
The mountains prevent the humidity and prevailing wind from reaching inland
This creates a rain shadow that means that areas behind the mountains are hot and arid forming a desert

Weathering and erosion

Weathering is when existing rocks are broken down leaving the sediments and fragments
Erosion is when existing sediments are transported away through
There can be many different types of weathering.
Physical weathering uses ice, water and heat
While chemical weathering used dissolution via acids in rain
You can also have biological weathering
Erosion is caused by agents of erosion working together to wear down the rocks
This can happen due to Gravity, Wind, Ice, Water

Physical weathering occurs when a rock is broken into smaller pieces by the action of water, wind, ice and other sediments.
Chemical weathering occurs when the minerals within a rock react with water, oxygen or acids in the environment forming new materials
Physical weathering
Physical weathering occurs when a rock is broken into smaller pieces by the action of water wind and other sediments.
No new minerals are formed existing materials are just broken into smaller pieces; therefore, it is a physical not chemical change.
Chemical weathering occurs when the minerals within a rock react with water, oxygen or acids in the environment forming new materials.
Because new minerals are formed this is a chemical change
Erosion is the breaking down of rock through the physical or chemical process
Transport is the movement of particles from their origin to its deposition point.
Deposition is where the layers may eventually form a sedimentary rock.

Sediments

When rocks are weathered, they leave behind particles called sediments.
There are many sizes of it.
Gravel 5cm-2mm - Big enough to feel it.
Sand 2mm-0.5mm - Feel grains but not individually.
Silt less than 0.06 – 0.004 Not visible but feels gritty.
Clay under 0.004 - Smooth and slippery

Environments of deposition

Different environments of deposition can occur
These environments can include: rivers, deltas, estuaries, deep oceans alluvial fans, dunes or beaches

As it slows down will be gravel then sand then silt then clay might not sand
Sediments are deposited in flat layers.
Oldest at base
Younger at top
Each layer can be interpreted to indicate the local conditions at time of deposition.
Can read the history of them.

Flowing water sorts of sediments by particle size
Usually, further sediments travel from the source the more sorted they are.
Larger particles need faster moving fluid to pick them up or carry them than finer particles.
Larger particles will settle out of a slower fluid before finer particles.
Disposition and energy
Consider a surge of water carrying all sixes of sediment from a landslide.
initially all sediment is moving.
large clasts settle first go gravel and sand deposit at the base.
sand settles next as the fluid slows.
silt rapidly deposits when the water becomes still.
clay slowly settles as still water sits.
Sediment is deposited in flat layers as the settle to the bottom.
Oldest sediments are at the base.
Younger at the top
Each layer can be interpreted to indicate the local conditions at the time of deposition.
A geologist can read the history from bottom to top.
The energy of the environment will influence the size of the particles that will be deposed their higher energy = particles
Flowing water sots' sediment by particle size
Usually, the further sediment travel from the source the more sorted they are
Well sorted rocks mean travel along way to be weathered.
Poorly sorted is a rock that have travelled not far and not weathered as much.
As the energy in a system change in a river as it flows towards the ocean, they sediment it is able to transport changes.
As energy falls larger sediment are deposited while smaller countries to move along
Greater transport therefore leads to better sorting.

Rounding

When sediment is moved, they bump around and collide with each other.
This wears grains down and causes them to become more rounded.
As sediment are transported and subject to high energy environment, they become more rounded.
This is because the repeated bumping and tumbling of sediment will cause then to be physically worn down.

Sediments to lithified rocks

Sediments can transform into sedimentary rocks through lithification
This occurs when a sediment is first deposited, buried, compacted then cemented by fluid circulation creating a new rock

Stratification and bedding

bedding refers to the layering seen in sedimentary rock
Layers can be.
Grai size
Colouring
Composition/mineralogy
Bed are thicker strata.
Generally greater than 1 mm thick
Can be up to meter thick.
Usually, coarse grained sand and gravel
Laminations are thin strata.
Less than 1 mm

Usually, finer grained sediment like silt and clay
Indicate changing energy during deposition such as seasonal variation
A variation of bedding can be Formed when huge event occurs such as a flood and a large amount of sediment is rapidly sorted
the cobbles and gravel drop forming breccial and conglomerate
then sands deposit forming sandstone
then silt and clays finally settle out forming mudstone and shale

A good example of lithification and stratification is sandstone formation
This occurs when layers of sand accumulate under the ocean and are compressed and lithified
Sandstone is around 20% of the earth's surface sedimentary record
They were made up of old shallow deans and ancient mountain chains

Sea level change

Environments of deposition can be different to the rock's current environment, one of the most prominent examples with sedimentary rocks is the sea level change
This variation of the sea level is caused by climate effecting the water cycle
Colder periods have more ice and a lower sea level
Hotter periods have the opposite
The retreat of water exposes these sedimentary rocks to the surface
One example is the Aral sea located in Kazakhstan and Uzbekistan, it was once the 4th largest lake in the world
Due to the diversion of the water by dams and canals by the soviets it has lost most of its water and increased in salinity

The rise of sea level is caused by three main factors: thermal expansion of seawater due to warming, melting glaciers and ice sheets, and increased ice melt from glaciers.

Tectonic uplift

Tectonic uplift can also expose new rocks to the surface
This happens when plates move and collide together forming a new mountain chain, at this time some of the old sea floor can be uplifted and deformed – THE PLAYDOUGH
A prominent example of this is Uluru
It is a geological inselberg or monadnock which is 3.6 x 2 km wide and is made of a mountain chain that was uplifted around 550Ma ago.
The sand that formed it was eroded from granitic mountain chain around 990Ma ago

Metamorphism

A metamorphic rock is a rock that forms when a pre-existing rock (Protolith) undergoes chemical and physical changes in response to heat and pressure
This mainly happens during the formation of mountain chains (Orogenesis)

Metamorphic rocks are rocks that have changed their form and composition due to high temperature, pressure, or chemical reactions.
They are formed from pre-existing rocks, which can be igneous, sedimentary, or other metamorphic rocks.

What happens during metamorphism.

Due to the heat and/or pressure a rock is under it can undergo either chemical or physical changes to its crystals arrangement altering the rock appearance and properties.
Recrystallization of minerals

- High temperatures allow the old bonds to break and new ones to form within a mineral structure
- This creates different shaped grains and increases the grain size

- This is a physical change

Reaction of minerals

- High pressures can cause low density mineral structures to collapse resulting in new stable minerals which are more dense
- The present minerals will change
- Can produce fluids from this process
- This creates chemical change
- E.g. Muscovite + Quartz > Sillimanite + Feldspar + Water

Consequences of having a dynamic planet

Changes across the planet are caused by the imbalance of energy between different systems
These changes mean that landscapes are constantly changing and evolving
Some of these processes are very slow, happening over millions of years while some are happening so fast that we can witness them
Some changes like earthquakes and eruptions are sudden and create a large range of hazards

Living on a Dangerous Planet

What are Natural Disasters

Natural disasters can be very dangerous, they can be responsible for loss of life and the destruction of property
They can be very rapid events
Some of these geohazards can be mitigated (If only partially) while some cannot
List of geohazards: Earthquakes, Volcanic eruptions, Mass movements (e.g., landslides), Tsunamis, Flooding, Cyclone / storm, Expansive soils, Sink hole, Wildfires, Lightning, Snow avalanche, Drought, Hail, Tornado, Earth material (asbestos, gas), Sand blasting and Coastal erosion

Natural Disasters are catastrophic events caused by natural processes of the Earth that result in significant damage to property, loss of life, and disruption to human activities. They differ from natural hazards as they have a direct and severe impact. Natural Hazards are natural phenomena that have the potential to cause harm or damage if they interact with human populations and structures.

Earthquakes

An earthquake is when a sudden release of built up pressure in the earths crust creates waves that radiate outwards from the source

Why do earthquakes occur

It happens when two faults slide past each other with a lot of friction
The point at the surface of the earthquake is called the epicentre, it is above the hypocentre
The more time that passes in-between earthquakes the more energy that builds up the larger the earthquake

Where do earthquakes occur

This happens as lithospheric plates are constantly moving, and they are constantly getting stuck and accumulating energy meaning when it slips it creates a shockwave
They mostly happen on plate boundaries
81% of large earthquakes happen on the ring of fire, 17% on the alpine belt

They can also happen in the centre of tectonic plates as there are small faults everywhere

Consequences of Earthquakes

They release energy which is expressed in magnitude
The Richter scale is used to measure this and goes from 0-10, each level of magnitude is 10x more than the last
Earthquakes cause ground shaking, ground rupture, landslides, liquefaction and tsunamis
Prediction of earthquakes is reliant on probability
The mitigation of damages requires peoples awareness of the hazard and safer building techniques

When an earthquake occurs a great deal of Kinetic energy is released as Seismic Waves. The destructive capacity and energy released can be measured using the Richter Scale and Moment Magnitudes.
Earthquake severity can be measured using the Richter Scale, this is a logarithmic scale going from 1-10.
There are several factors that determine the destruction of an earthquake.
Location – An earthquake that hits a more populated area is more likely to do more damage than one in an unpopulated location
Magnitude - Scientists assign a number to represent the amount of seismic energy released by an earthquake. The Richter magnitude scale is logarithmic, so each step up represents an increase in energy of a factor of 10. The more energy in an earthquake, the more destructive it can be.
Depth - Earthquakes can happen anywhere from at the surface to 700 kilometres below. In general, deeper earthquakes are less damaging because their energy dissipates before it reaches the surface.
Distance from the epicentre - The epicentre is the point at the surface right above where the earthquake originates and is usually the place where the earthquake's intensity is the greatest.
Local Geological Conditions - The nature of the ground at the surface of an earthquake can have a profound influence on the level of damage.
Secondary Effects - Earthquakes can trigger landslides, fires, floods or tsunamis.
Architecture - Even the strongest buildings may not survive a bad earthquake, but architecture plays a huge role in what and who survives a quake.

Long-term Impact: Economic Crises

- Earthquakes can lead to significant economic crises in the affected region due to damage to infrastructure, disruption of business activities, and loss of livelihoods. Businesses may struggle to recover, leading to job losses and reduced economic output. Rebuilding infrastructure and homes can strain government resources, potentially leading to long-term economic downturns or budget deficits.

Short-term Impact 1: Liquefaction

- Liquefaction occurs when saturated soil temporarily loses strength and stiffness during shaking, causing it to behave like a liquid. This can lead to ground subsidence, tilting or sinking of buildings and infrastructure, and disruption of utility lines.

Short-term Impact 2: Building Damage

- Buildings are particularly vulnerable during earthquakes, especially in regions with inadequate building codes or where older structures predominate. Damage can range from minor cracks to complete collapse, impacting residential, commercial, and industrial buildings.

Mitigating earthquake damage can be approached in various ways, but here are two effective strategies:

- Building Design: Constructing buildings with earthquake-resistant designs. Techniques include using flexible materials, base isolators, and bracing to enhance a building's ability to withstand seismic forces.

- Early Warning Systems: Implementing early warning systems that detect seismic activity and alert people before the shaking arrives can save lives and reduce injuries. These systems provide people time to take cover and for infrastructure to shut down automatically, minimizing damage.

Earthquake Hyperfocus

Earthquakes can also be described by their focus and epicentre.
The earthquake hypo-focus refers to the actual location within the Earth where the seismic energy is released or originates.
It is the point underground where the fault slip occurs, resulting in the generation of seismic waves.
The focus can be at various depths, ranging from shallow depths near the Earth's surface to deeper depths within the Earth's crust or mantle.
The depth of the focus is an essential factor that influences the characteristics and potential impacts of an earthquake.

Earthquake Epicentres

On the other hand, the epicentre refers to the point on the Earth's surface directly above the earthquake hypo-focus.
It is the location on the ground where the seismic waves are most strongly felt or where the greatest shaking occurs.
The epicentre is determined based on the analysis of seismic data recorded by seismometers at different locations.
By triangulating the arrival times of seismic waves, seismologists can estimate the epicentre and its corresponding geographical coordinates.
When an earthquake occurs, energy transmits outward from the focus in the form of seismic waves. As seismic waves travel through the Earth's crust, they interact with various geological materials, which cause them to lose energy and diminish in amplitude. This process is known as attenuation and can be influenced by several factors.

Mitigating the Effects of Earthquakes

Building Codes and Infrastructure:

- Seismic Design:
- Standards: Implementing construction standards that ensure buildings can withstand seismic forces. This includes designing structures that are flexible and can absorb shock.
- Materials: Using materials and techniques that provide flexibility and strength. This helps in reducing the risk of building collapse during an earthquake.
- Retrofitting:
- Strengthening: Upgrading older buildings and infrastructure to meet current seismic standards. This includes reinforcing foundations, walls, and roofs.
- Support Systems: Installing braces, shear walls, and base isolators. These systems help in stabilizing structures and reducing damage during an earthquake.
- Design: Ensuring gas, water, and electricity systems are designed to move with seismic activity. This helps in preventing utility failures and reducing the risk of secondary disasters.
- Safety Features: Incorporating automatic shutoff valves and flexible connections. These features help in reducing the risk of fires and leaks during an earthquake.

Early Warning Systems:

- Seismic Sensors:
- Network: Deploying a network of sensors to detect and provide early warnings of earthquakes. These sensors help in identifying seismic activity quickly.

- Data Collection: Using real-time data to alert authorities and the public. This helps in initiating timely evacuation and response measures.
- Alert Systems:
- Communication: Public alert systems through text messages, alarms, and broadcasts. These alerts provide critical information to communities.
- Coordination: Ensuring timely and accurate dissemination of information. This helps in reducing confusion and ensuring orderly evacuation.

Land Use Planning:

- Zoning Regulations:
- Risk Assessment: Avoiding construction in high-risk areas, such as fault lines. This helps in reducing the risk of damage during an earthquake.
- Development Policies: Enforcing zoning regulations to minimize risk. This includes restricting development in vulnerable areas.
- Open Spaces:
- Evacuation Areas: Designated open spaces for evacuation and temporary shelters. These spaces should be easily accessible and well-maintained.
- Accessibility: Ensuring these areas are easily accessible during an emergency. This helps in facilitating quick and safe evacuation.

Preparedness:

- Public Education: Informing communities about earthquake safety and preparedness. This includes understanding how to secure heavy furniture and preparing emergency kits.
- Drills: Regular practice of evacuation and emergency response plans. These drills should involve all community members and be coordinated with local authorities.
- Emergency Kits:
- Supplies: Encouraging households to maintain emergency supplies, including food, water, first aid, and tools. This helps in ensuring readiness for immediate needs after an earthquake.
- Readiness: Ensuring individuals and families are prepared for immediate needs after an earthquake. This includes having a plan for reunification and communication.

Response and Recovery:

- Rapid Response Teams:
- Training: Preparing professionals for immediate post-earthquake assistance. This includes search and rescue, medical care, and providing shelter and food.
- Deployment: Ensuring quick and effective deployment of response teams. This helps in saving lives and reducing damage.
- Reconstruction Plans:
- Strategy: Developing strategies for rebuilding and recovery. This includes assessing damage, prioritizing critical infrastructure, and ensuring community involvement.
- Support: Aiding affected communities to restore normalcy quickly. This includes financial aid, mental health support, and long-term rebuilding efforts.

Earthquakes in Australia

Australia is in the centre of its plate
The Australian plate is the fastest moving continental land mas on earth, it is colliding with the Eurasian and pacific plates
It is also a very large plate
There are more than 350 fault scarps in Australia
There are more than 100 earthquakes with a magnitude of 3 or greater a year and 1 magnitude 6 earthquakes every 10 years

Earthquake hazards were not considered in building codes in Australia until the 1990s
Perth has a large number of these earthquakes as there is very old crust there with lots of faults as well as the darling scarp

Perth has a large number of earthquakes; this is because the Perth/Peel region is located next to the Yilgarn Craton. It is a very old section of the continental crust around 2.5-2.9Ga. The Australian plate shifts upwards towards the Pacific and Eurasian plate. The age combined with the pressure of movement creates intra-plate fault lines. The intra-plate fault lines create earthquakes.

Volcanoes

A volcano is a conduit through the crust from which gases and magma can escape
The size and shape of the volcano can depend on the eruptions
Some eruptions can be calm with slow moving lava flows while some are violent and explosive
These can be classified as red v grey eruptions
Volcanoes can be active, dormant, or extinct

Volcanoes are openings through which hot gasses, hot rocks and ash from the earth's mantle can escape to the surface.
They are usually mountains made of the erupted material.
Some come out of fissures (long cracks in the crust)
Magma is molten rock withing the earth's crust and lava is this material once it has erupted to the earth's surface.
There are two main types of volcanoes, effusive and explosive.
These types of volcanoes both have different properties based on where they are located.

Why do volcanoes occur

Volcanoes occur when the earth is trying to equilibrate the temperature between the inside and outside, this means that solid hot material will rise upwards due to convection
This solid material with turn into magma due to a decrease in pressure, change in temperature or addition of volatiles

They are caused when the mantle material forces its way through the cracks in the lithosphere and weaknesses in the crust.

Where do they form

They mostly occur on the boundaries of plates but can still happen intraplate due to magma plumes or local tectonics

Effusive Volcanoes

An effusive volcano is a volcano where the eruptions are mostly lava, they can also be called shield volcanos.
They are found at divergent boundaries (mid ocean ridges and rift zones) or hot spots.
This lava is mafic and is of low viscosity, this causes it to be able to flow and run out of the cone of the volcano.
This lava is mafic due to the fact that it quicky rises though the crust, having little time for the mafic minerals to crystalize and sink down.
This hot temperature at the time of eruption means that the lava has a very low viscosity and so any gasses built up inside it can escape.

Explosive Volcanoes

An explosive volcano is a volcano where the eruptions are violent and made up of ash, lava, gasses and the material making up the volcanos cone, these volcanoes can also called composite/stratovolcanoes.
They are found at convergent boundaries (Oceanic-to-continental or Oceanic-to-oceanic).
This magma is felsic and is of high viscosity, this causes the lava to be 'thick and gluggy' meaning that the magma builds up within the volcano.
This lave is felsic due to the fact that as it rises It will eat the crust as it moves up becoming felsic
This cooler (relatively it's still around 800-600 degrees) magma means that gasses built up within the volcano cannot escape and build up until it erupts and in the prosses it blasts itself apart.

Consequences of volcanoes

Volcanoes are very dangerous and have killed around ¼ of a million people in the last 2000 years
Considering this statistic quite a few major cities are built near volcanoes
Volcanoes can pose threats in the forms of
Lava flows, pyroclastic flows, the dispersal of ash into engines, lahars, the asphyxiation of people through toxic gasses, the creation of volcanoes and tsunamis

Mitigating the Effects of Volcanic Eruptions

Monitoring and Early Warning:

- Seismic Monitoring:
- Detection: A network of seismic sensors is used to detect volcanic tremors and earthquakes. This helps in predicting potential eruptions.
- Analysis: Data from seismic monitoring is analysed to understand volcanic activity and potential eruption signs.
- Gas Emissions Monitoring:
- Volcanic Gases: Analysis of gases like sulphur dioxide is conducted to identify changes in volcanic activity. Increased gas emissions can be an indicator of an impending eruption.
- Remote Sensing: Satellites are used to monitor gas emissions and land deformation. This provides real-time data for early warning systems.
- Satellite Surveillance:
- Observation: Satellites are used to monitor volcanic activity and changes in the landscape. This helps in identifying signs of an impending eruption.
- Data Collection: Real-time information from satellites is crucial for early warning and disaster preparedness.

Land Use Planning:

- Risk Areas: Establishing exclusion zones around volcanoes where development is restricted to minimize risk. This prevents habitation in high-risk areas.
- Regulations: Enforcing land use policies to prevent construction in areas prone to volcanic hazards.
- Evacuation Routes and Shelters:
- Planning: Clearly marked and accessible routes and shelters for communities at risk. These should be well-maintained and regularly updated.
- Infrastructure: Building and maintaining shelters for evacuees. These shelters should be equipped with necessary supplies and accessible to all community members.

Infrastructure:

- Lava diversion barriers are constructed to redirect lava flows away from populated areas. They help in protecting communities from lava damage.
- Construction: These barriers are designed to withstand the flow and heat of lava. They are strategically placed to guide lava away from critical areas.
- Strengthened Buildings:
- Design: Constructing buildings to withstand ashfall, pyroclastic flows, and volcanic debris. This includes using materials that can resist volcanic hazards.
- Retrofitting: Strengthening existing buildings to meet safety standards. This helps in reducing the risk of damage during an eruption.

Preparedness:

- Public Education:
- Awareness Programs: Informing communities about volcanic hazards, warning signs, and safety measures. This includes understanding evacuation procedures and preparing emergency kits.
- Safety Protocols: Educating the public on what to do before, during, and after an eruption. This helps in reducing panic and ensuring orderly evacuation.
- Emergency Drills:
- Practice: Regular evacuation drills to ensure readiness. These drills should involve all community members and be coordinated with local authorities.
- Coordination: Ensuring that local authorities and communities can respond effectively. This includes having clear communication channels and response plans.

Volcanoes in Australia

There are currently no active volcanoes on mainland Australia, the only one is on heard island in the south ocean
There is important volcanic history throughout Australia's geological timeline
The newest volcanic Provence was active from around 4.5 – 3k years ago

Mass Movements

They are when the failure of a slope causes debris to move downwards, they are landslides
Mass movements can include:

- Rock falls
- Slumps
- Rockslides
- Debris flows
- Soil creeps

Why do mass movements happen

Mass movements happen when a slope fails when it is too steep and unstable for the conditions the materials of the slope
They occur when the cohesion of the underlying material is weakened due to the adding of water into cracks, the orientation of the bedding, an earthquake, an increasing slope, the removal of the base of a slope

Where do mass movements happen

They are likely to happen wherever there is a slope from hills to mountains
They are more frequent in areas of high precipitation and anthropogenic change, elevated coastlines, seismic, volcanic and snowy regions
They are very likely to occur where ones have occurred in the past

The consequences of mass movements

One of the major consequences of a landslide is the destruction of buildings and infrastructure
They can be stopped by draining water in high risk areas, increasing the vegetation to stabilise the slopes, adding nets to stop minor rock falls, creating terrace steps and bolting rocks in place

One example of this is the 1999 Vargas Mudslides
This event occurred due to torrential rains that flooded the mountainous regions of Venezuela
This caused a flash flood, which triggered the debris flow and the mudslides
Some areas were buried under 3m of mud
10-30 thousand people were killed

Tsunamis

Tsunamis are a series of large waves within a body of water that is caused by large scale displacement
They don't resemble normal waves, they act like a rapidly rising tide
They generally consist of a series of waves along a period of minutes to hours
Their length makes them hard to detect in the ocean

Tsunamis are powerful and destructive ocean waves that can cause widespread devastation along coastlines. They are typically generated by underwater disturbances, such as earthquakes, volcanic eruptions, or landslides.

Why do tsunamis occur

Tsunamis can occur due to multiple reasons.
One reason is if there is a submarine earthquake at a fault, this is the most common reason
A submarine landslide can cause the rapid displacement of water
A volcanic eruption can cause an explosion underwater
A large meteor impact into the water can cause a tsunami to occur

When an earthquake occurs beneath the ocean floor, it can trigger a series of seismic sea waves. The vertical movement of tectonic plates generates a tremendous amount of energy, transferring it to the water above. This energy is then transmitted as a series of long-wavelength waves, traveling through the ocean at high speeds. Alternatively, an explosive volcanic eruption or a marine landslide may be the cause of water disturbance and source of energy that leads to a tsunami, though they then form and propagate in the same way.

As these waves propagate through the ocean, they can travel vast distances without losing much energy. In the deep ocean, tsunamis are characterized by long wavelengths and relatively low wave heights, often going unnoticed by ships and boats. However, as the waves approach shallower coastal areas, they begin to slow down, and the wave height increases significantly.

When a tsunami reaches shallow coastal regions, a tsunamic MAY cause coastal waters to "suck back" toward the ocean. It then undergoes a process called "run-up": as the wave hits the shallower sea floor, the wavelength shortens and amplitude increases, towering over the normal sea level and flooding inland. The destructive force of the waves is amplified by their sheer volume and momentum, resulting in catastrophic damage to coastal communities and infrastructure.

Where do tsunamis occur

Tsunamis occur everywhere around the coastlines; they are more likely to occur around the pacific ocean and Indonesia do to their proximity to the ring of fire
The north of Australia has a moderate risk of tsunamis due to it being proximal to subduction zones

The consequences of tsunamis

One of the most well-known consequences of a tsunami was the meltdown of the Fukushima nuclear power plant
This disaster occurred when a M9 earthquake occurred 130km from shore
This created a 30m high tsunami wave
This tsunami destroyed more than 100,000 buildings, knocked out power across the region, killed 15.5 thousand people and caused more than ½ million people to lose their homes
The earthquake shook the Fukushima reactor which was shut down due to the earthquake risk.
The tsunami flooded the diesel generator, and the lost power meant there was nothing to run the cooling pump
This meant the cooling water overheated triggering explosions in ¾ of the reactors releasing nuclear material into the environment

Mitigating the Effects of Tsunamis

Efforts to mitigate the risks associated with tsunamis involve a combination of early warning systems, public education, and coastal planning. By monitoring seismic activity, detecting underwater disturbances, and disseminating timely warnings, authorities can help coastal communities prepare for these destructive waves, potentially saving lives and minimizing damage.

Early Warning Systems:

- Tsunami Detection Buoys: These buoys are deployed in the ocean to detect changes in water level and send data to monitoring centres. They play a crucial role in early detection and warning.
- Seismic Sensors: These sensors detect underwater earthquakes that may generate tsunamis. They help in quickly identifying potential tsunami threats.
- Tide Gauges: Tide gauges measure sea level changes and provide real-time data. This information is vital for confirming the presence of a tsunami wave.
- Communication:
- Alerts: Alerts are issued via various channels such as sirens, text messages, radio, television, and internet. These alerts help communities to evacuate promptly.
- Community Outreach: Educating coastal communities about warning signs, such as unusual ocean behaviour, and evacuation procedures can save lives.

Infrastructure:

- Sea Walls and Barriers:
- Purpose: Sea walls and barriers are constructed to protect coastal areas by reducing the impact of tsunami waves. They act as a first line of defence.
- Design: These structures are designed to withstand the force of tsunamis and prevent water from reaching inland areas.
- Building Codes:
- Regulations: Ensuring that buildings in tsunami-prone areas are designed to withstand flooding and wave impact. This includes elevating structures and using materials that can resist water damage.
- Elevated Buildings: Constructing buildings on stilts or elevated platforms to avoid flood damage. This helps in reducing the risk of water damage during a tsunami.

Preparedness:

- Public Awareness Campaigns: Informing communities about tsunami risks, warning signs, and safety measures. This includes understanding natural warning signs like an earthquake or receding water.

- Drills: Regular evacuation drills to ensure that people know how to reach safe areas quickly and efficiently.
- Evacuation Plans:
- Routes: Clearly marked evacuation routes leading to higher ground or inland. These routes should be well-maintained and free of obstacles.
- Shelters: Designated safe shelters for evacuees. These shelters should be stocked with necessary supplies and accessible to all community members.

Environmental Management:

- Mangrove and Coral Reef Conservation:
- Natural Barriers: Mangroves and coral reefs act as natural barriers that reduce wave energy and provide coastal protection. They help in minimizing the impact of tsunamis.
- Restoration Projects: Initiatives to restore and protect these natural barriers can enhance their ability to mitigate tsunami effects. This includes replanting mangroves and protecting coral reefs from damage.

Monitoring Tsunamis

The Boxing Day tsunami occurred on December 26, 2004, when a massive undersea earthquake with a magnitude of 9.1 struck off the coast of Sumatra, Indonesia. The earthquake triggered a tsunami that spread across the Indian Ocean. The powerful waves, reaching heights of up to 30m, caused widespread destruction, claiming the lives of approximately 230,000 people. Entire coastal communities were decimated, and the disaster brought attention to the urgent need for early warning systems and improved disaster preparedness in vulnerable regions.

Promptly detecting and monitoring these potentially destructive waves is crucial for issuing timely warnings and minimizing the loss of life and property. There are several ways in which the worst impacts of tsunami can be avoided or mitigated, and it is the job of tsunamic early warning centres to monitor and alert populations about tsunamis.

Meteorological hazards

Any one meteorological hazard can have very different factors influencing it in different countries around the world. For this reason, this chapter will focus specifically on Australia. The meteorological hazards which typically have the most impact in Australia include:

- Droughts
- Floods
- Bushfires
- Heatwaves
- Storm cells
- Tropical cyclones

At their worst, these events can have enormous impacts on agriculture, infrastructure, biodiversity and the economy.
Due to the many fatalities resulting from these hazards during Australia's short period of European settlement, these meteorological hazards influence our cultural practices, settlement patterns and government regulations.
These natural hazards also operate on different time scales and geographic scales. Some develop slowly and can have impacts that drag on for months or years over huge areas (e.g. drought).
Others can develop then dissipate in a matter of hours yet cause substantial impacts over small areas (e.g. hailstorms).

Heatwaves

A heatwave is three or more days of unusually high maximum and minimum temperatures in an area
Heatwaves effect large to medium impact areas
Heatwaves happen irregularly during the summer.
Heatwaves happen over short term time scale of a few days

Bushfires

Bushfires occur when high temperatures and prolonged dry conditions lead to wildfires on a large scale
This creates many hazards such as smoke haze
They can be natural or anthropogenic
If you see wildfire, just run to your car and drive

Time Scale:

- Bushfires happen over short term time scale of a few days
- However, some in some circumstances they can last for weeks (E.g. 2019 Fires)

Frequency:

- Bushfires are typically cyclical.
- They occur frequently in regions with dry climates and significant vegetation.

Area Impacted:

- Bushfires effect small to medium scale rural areas, national parks and highly vegetated urban areas
- However, in some extreme circumstances then it can cover large areas of land (E.g. 2019 Fires)

Description:

- Fires that occur in heavily vegetated areas are called bushfires. They are normal events around summers.

Bushfires can range in intensity from small, controlled burns to large out of control burns
Contributing Human Activities

- Due to anthropogenic climate change we are having increases in dry periods in some areas, an increase in extreme heat days, and a lengthening of the bushfire seasons
- Another major factor contributing to the impact of bushfires is the spread of residential dwellings in forested areas.
- An appreciation of Australian bush landscapes has seen an increase in housing construction in bushfire prone areas, such as on the fringes of major cities and in coastal and mountain areas.
- Such houses are at great risk during bushfires, even if they are designed with fire prevention in mind.

Benefits of bushfires

- Stimulating Seed Germination as certain plant species require the heat from fires to trigger seed germination.
- Fires clear thick undergrowth, allowing sunlight to reach the forest floor and encouraging the growth of native vegetation.
- Fires help recycle nutrients back into the soil, which can rejuvenate native vegetation.
- Controlling Pests and Diseases as fires can eliminate invasive weeds, pests, and diseases that may harm native plants.
- Creating Habitats as burnt trees and logs can provide habitats for birds, mammals, and insects.
- Maintaining Ecological Balance through periodic fires help maintain the ecological balance by clearing dead organic material and promoting new growth.

- Indigenous populations have used controlled burns for thousands of years to manage the landscape and promote biodiversity.

Droughts

Time Scale:

- Long term time scale of around months or years.

Frequency:

- Happens over a cyclic timescale.
- Australia wide, average there is drought once every 17 years at a given locality, though many areas experience droughts more frequently.
- Climate modelling suggests that this average may shorten considerably in coming years.
- Widespread drought in Australia has historically been linked to El Nino conditions
- It can also be linked to positive Indian Ocean dipole conditions.

Area Impacted:

- It happens on a medium to large scale.
- Drought can occur on a smaller scale, usually when some districts miss out on the drought relieving rains that are experienced by surrounding areas.

Description:

- A drought is rainfall over a three-month period being in the lowest decile (10%) of all the recorded measurements for that region in the past. Australin is known for having droughts as part of the normal long term climate cycle.

Contributing Human Activities:

- Anthropogenic climate change can contribute to drought by increasing average temperatures in a region, as well as the number of extremely hot summer days which that region experiences.
- Evaporation rates increase as a result. Lakes and rivers dry up more quickly, but the biggest problem is with soil drying out.
- If agricultural paddocks lose too much moisture, crops become stunted or may perish altogether. Irrigation from subsurface water is used when available to replace the missing rainfall.
- This diminishes water supplies for the environment causing lakes, rivers and underground water supplies to reduce in both volume and quality.
- Large scale trees felling to clear pasture by European farmers is another factor that continues to contribute to drought.
- With trees in place, much of the ground layer of a forest is shaded from direct sunlight and kept relatively moist.
- As trees were removed from what became huge farming regions across Australia, the soil became much more exposed to direct sunlight and therefore more prone to drying out.
- Tree removal also increased erosion of the organic layer of mulch on top of soils, leaving them even more exposed to drying out.
- Unsuitable farming and grazing methods in Australia have also contributed towards making the impacts of any drought worse.
- The first European farmers to arrive in Australia applied the same strategies that they used in Europe, involving stripping away surface vegetation, ploughing up and turning the soil.

- They did not appreciate the fragility of the much older Australian soils or the different requirements of the very different climate.
  Instead of the frequent gentle rains which they were accustomed to, long dry periods meant exposed soil would dry up and be blown away as dust storms.
- If it did rain, heavy storms would often wash much of the topsoil away in exposed paddocks.
- Overstocking hard hoofed animals in grazing paddocks could compact the soil and strip away the vegetation that was holding the soil together.
- All these different practices that led to erosion, soil compaction and loss of surface organic matter have left a legacy of even poorer soils that are less able to retain moisture and resist drought.

Storms Cells

Time Scale:

- Short term time scale
- Storm cells typically form and dissipate within a few hours, though they can occasionally last longer.

Frequency:

- Variable frequency
- Storm cells can occur frequently during certain seasons, particularly in the warmer months.
- They can happen multiple times a year in certain regions, especially in areas prone to thunderstorms

Area Impacted:

- Small to medium scale
- Storm cells generally affect localized areas, but a severe storm can impact a broader region, depending on its size and intensity.

Description:

- A storm cell is a compact and short-lived weather phenomenon typically associated with thunderstorms.
- These cells can produce a range of weather effects including heavy rain, hail, strong winds, and lightning.
- Severe storm cells can lead to flash flooding or wind damage

Contributing Human Activities

- The heat generated in urban areas can intensify storm cells, sometimes leading to more severe weather events.
- Tall buildings can influence wind patterns, contributing to the formation of localized storm cells.
- Warmer atmospheric conditions caused by climate change can lead to more intense storm cells by increasing the energy available in the atmosphere, potentially leading to more severe thunderstorms.

Tropical Cyclones

Time Scale:

- Medium term time scale
- Tropical cyclones can last from a few days to over a week, depending on their path and strength.
-

Frequency:

- Tropical cyclones typically occur during the warmer months, particularly from November to April in the Southern Hemisphere.
- The frequency can vary significantly from year to year.

Area Impacted:

- Large Scales
- Tropical cyclones can affect vast areas, spanning hundreds of kilometres.
- Coastal regions are most vulnerable, but the impacts can extend inland depending on the cyclone's strength and speed.

Description:

- A tropical cyclone is a powerful, rotating storm system characterized by strong winds, heavy rain, and thunderstorms.
- They form over warm ocean waters and can lead to widespread damage through high winds, storm surges, and flooding.
- In Australia, these are commonly referred to as cyclones.

Contributing Human Activities

- Warmer sea surface temperatures due to climate change can lead to more intense tropical cyclones.
- Increased atmospheric moisture also contributes to heavier rainfall during these events.
- Human settlement along coastlines increases vulnerability to the impacts of tropical cyclones.
- The removal of natural vegetation like mangroves, which can act as a buffer against storm surges, exacerbates the damage caused by cyclones

Flooding

Flooding occurs when a usually dry area is covered in water
This is caused by heavy rainfall or the oversaturation of soils
This causes damage in urban environments when drainages systems cannot cope with the amounts of water
Many factors can influence the magnitude of floods

Time Scale:

- Short term time scale of days to weeks

Frequency:

- Repeats at irregular times over several years in most regions.
- Yearly during the wet season in the tropics

Area Impacted:

- This can range from small to large areas.
- A small flash flood can affect a single area, a tropical low can affect entire regions
- Due to Australia’s flat terrain, it can take a while for floods to drain away and can be very widespread

Description:

- Floods are a short and periodic natural event that occurs because of the natural cyclic weather patterns.

- Floods occur when rainfall is so heavy that normal water channels spill over and cover what is usually dry land.
- Flooding along coastlines can also be the result of unusually high tides
- Floods are a regular part of the drought-flood cycle typical in much Of Australia

Contributing Human Activities:

- Anthropogenic climate change is slowly increasing the strength of tropical cyclones and rainfalls that causes floods.
- This creates an increased risk of flooding in affected areas
- Urbanisation can also worsen flooding as it removes soil, which can help to retain water.
- This slows down the sub-surface movement of water, leading to slowed discharge rates into waterways
- Urban land is predominantly paved, concreted, built on or sealed by bitumen.
- The area of exposed soil available to absorb water is radically reduced.
- Gutters on buildings and roads to rapidly channel water into drains, which quickly carry water into concreted waterways which then carry water into rivers leading to flooding of urban and natural waterways
- Damming rivers can have a long-term impact on floodplains as slowly nutrients that is needed in the soil

How do we manage floods:

- Levee banks and dams are constructed to control the flow of water during flood events, reducing the size and impact of floods on towns and agricultural areas.
- Levees act as barriers to prevent water from spilling over into populated or agricultural areas, while dams can store excess water and release it gradually, controlling downstream flooding.
- Floodgates are used to control the flow of water, especially in urban areas.
- They can be opened or closed to manage water levels, particularly during high tide or heavy rainfall events.
- Floodway's are designated areas designed to safely channel excess water away from populated areas, allowing it to flow overland during flood events.
- These floodway's reduce the pressure on river systems and help prevent water from inundating homes and infrastructure.
- Restoring natural floodplains, allowing rivers to reclaim parts of their historic floodplains, which can act as natural sponges, absorbing excess water during floods.
- This reduces the impact of floods downstream and also supports biodiversity by creating rich, fertile habitats for wildlife

What are the benefits of floods:

- Torrential rain during monsoons causes weathering and mass erosion of highlands in river watersheds.
- This increased volume and velocity of the runoff increase the rivers capacity to transport sediments.
- In the lower reaches of the river fine silt and clay sediments will eventually deposit onto floodplains as the river overflows its banks onto the flood plain.
- Silt and clay increases water and nutrient holding capacity of soils for improved agriculture and rejuvenation of natural ecosystems soils

Hail

Hail occurs when cold rain is carried upwards in a storm by a strong wind, this water is supercooled.

When it impacts with ice particles they grow into hailstones
They fall down under their own weight
They can be dangerous due to the weight and the speed of the ice falling down
Park the car in a garage

Volcanoes of Earth and the solar system

What are volcanoes (Repeat)

A volcano is a conduit through the crust from which gases and magma can escape
The size and shape of the volcano can depend of the eruptions
Some eruptions can be calm with slow moving lava flows while some are violent and explosive
These can be classified as red v grey eruptions
Volcanoes can be active, dormant, or extinct

Volcanoes are openings through which hot gasses, hot rocks and ash from the earths mantle can escape to the surface.
They are usually mountains made of the erupted material.
Some come out of fissures (long cracks in the crust)
Magma is molten rock withing the earths crust and lava is this material once it has erupted to the earths surface.
There are two main types of volcanoes, effusive and explosive.
These types of volcanoes both have different properties based on where they are located.

Why does magma form

Contrary to the diagrams in primary school the earth does not float on a sea of molten rock, if this were the case earths rotation would flatten the planet into a disk
The earth's interior is largely solid.
The occurrence of both extrusive and intrusive igneous through many different ages and locations and modern volcanoes mean that melting is a constant still continuing process

Why do volcanoes occur (Repeat)

Volcanoes occur when the earth is trying to equilibrate the temperature between the inside and outside, this means that solid hot material will rise upwards due to convection
This solid material with turn into magma due to a decrease in pressure

They are caused when the mantle material forces its way through the cracks in the lithosphere and weaknesses in the crust.

Why does magma rise

Mostly magma moves upwards away from the site of melting
Magma rises for 2 main reasons:
The first is that buoyancy means the magma will rise upwards like a hot air balloon as the near molten rock is less dense than the surrounding rock
The second is that the weight of the surrounding more solid rocks generate pressure that squeezes the magma upwards, (same process as your feet sinking in mud)
Essentially the mud squeeze and balloons

Types of eruptions

There are 2 main types of volcanic eruptions with many different sub types
The types of eruptions depend on the composition of the magma

The richer in silica and the more water content located in the magma the more explosive it is due to the thickness of the magma trapping gasses
The more time spent within the crust the more time it has to become silica rich and a felsic magma instead of igneous

The types of eruptions depend on speed at which the magma rises and composition of the magma
If the magma rises slowly, it will become felsic magma due to the assimilation of country rock as it rises and the crystallisation of mafic minerals, this causes the lava to have a high viscosity being 'thick and gluggy' meaning that the gas builds up within the volcano before violently exploding out causing a grey eruption.
If the magma rises quickly, it will stay as mafic magma due to it not assimilating country rock as it rises through the crust. It stays at a low viscosity due to it not absorbing silica, this causes it to be able to flow and run out of the cone of the volcano not trapping in the gasses, causing it to be a red eruption.

Effusive Volcanoes (Repeat)

An effusive volcano is a volcano where the eruptions are mostly lava, they can also be called shield volcanos.
They are found at divergent boundaries (mid ocean ridges and rift zones) or hot spots.
This lava is mafic and is of low viscosity, this causes it to be able to flow and run out of the cone of the volcano.
This lava is mafic due to the fact that it quicky rises though the crust, having little time for the mafic minerals to crystalize and sink down.
This hot temperature at the time of eruption means that the lava has a very low viscosity and so any gasses built up inside it can escape.

Explosive Volcanoes (Repeat)

An explosive volcano is a volcano where the eruptions are violent and made up of ash, lava, gasses and the material making up the volcanos cone, these volcanoes can also called composite/stratovolcanoes.
They are found at convergent boundaries (Oceanic-to-continental or Oceanic-to-oceanic).
This magma is felsic and is of high viscosity due to the assimilation of country rock as it rises, this causes the lava to be 'thick and gluggy' meaning that the magma builds up within the volcano.
This cooler (relatively it's still around 800-600 degrees) magma means that gasses built up within the volcano cannot escape and build up until it erupts and in the prosses it blasts itself apart.

Icelandic volcanoes

Iceland is unique in the fact that it straddles both a conventional hotspot and a mid ocean ridge meaning that it is a constant source of runny basaltic magma
This means that Iceland has a fissure stile of eruption where runny basaltic lava will flow out of faults and create large basaltic plateaus

An example of an eruption is the eruption of Mt Laki
In 1783 Mt Laki erupted for 8 months straight releasing large amounts of aerosols and gasses into the atmosphere
It caused crop failures across Europe and killed around 20% of the population
It also covered most of Europe with a large amount of fog and clouds

This created incredibly cold winter conditions across Europe followed by a series of extreme weather events
It led to several years of famine

Large igneous provinces

An igneous province is the accumulation of basaltic rocks over millions of km_2 and the formation of traps
Currently only eroded remnants of these provinces remain
Most of them were created over a very short lifespan of a few Ma
They are intrinsically linked to continental breakup
They emit large amounts of gasses during formation which cause mass extinctions (Siberian Traps)
An example of this is the Australian Kalkarindji province which was formed around 511 Ma
Its creation caused the first extinction event of the Phanerozoic

Hawaiian eruptions

Hawaiian eruptions happen due to hotspots
A hotspot is created due to the convection of the mantle
These types of eruptions are generally very gentle constant eruptions that build shield volcanoes
They produce rivers of basaltic lavas that are very fluid with very low Si and gas content
They can have lava lakes, Fire fountains and rivers of lava flowing above and below ground

The best example of this is the volcanoes on Hawaii
They are formed by a 70 Ma old hotspot
The island itself is around 1 Ma
Hawaii has the 3 most active volcanoes on the planet
Mt Kilauea (Currently active) Mona Loa (Last eruption 1984), Mona Kea (Last eruption at 4Ka) and Hualalai (Last eruption 1801)
Currently a new volcanic island is being formed below the sea

Another example of a hotspot volcano is Olympus Mons
Olympus Mons is a huge shield volcano on mars
It is around 25km high making it the tallest mountain in the solar system and it reaches 624km wide at its base
You can fit 100 Mona Loa's (earths largest volcano) into Olympus Mons
Its eruptions last a lot longer due to the absence of plate tectonics on mars and lower gravity
Its youngest eruption is around 150-100Ma
It produces very basaltic lavas like Hawaii
The top of the volcano consists of 6 nested calderas

Strombolian Eruptions

A strombolian eruption is an eruption that consists of pyroclasts, pyroclastic flows and lava flows
They are named after Mt Stromboli
Mt Stromboli is located in the north of Sicily; it is a composite stratovolcano that has been active for the past 5,000 years

Vulcanian Eruptions

A vulcanian eruption is similar to a strombolian eruption except there is a greater amount of pyroclastic flows
This is due to increased explosivity caused by gas buildups and volatile contents formed from local subduction

Scoria Cones

Scoria cones or cinder cones are one of the most abundant types of volcanos
They are made entirely of basaltic tephra (composed of scoria and bombs)
They usually only have a single period of eruption meaning they are monogenic
The cones are symmetrical and somewhat small
They are very easy to climb
They are abundant in the newer volcanic province in Australia -> Mt Elephant (Djerrinallum) and Mt Ieura
One of the best examples is the Paricutin eruption which erupted into a farmer's field while he was working from scratch
Djerrinallum means Hill of Fire, this suggests that aboriginals witnessed it erupt

Phreatic Eruptions

A phreatic eruption occurs when hot lava comes into contact or heats the surrounding colder groundwater
This causes the water to turn into steam and increases the pressure until there is an explosion
In this type of eruption there is no ash or magmatic material added just the explosion of the surrounding country rock

Phreatomagmatic Eruptions

A Phreatomagmatic eruption occurs when the magma involved with the explosion is also turned into ash which deposits on the ground
The ash if formed when magma rapidly fragments into ash particles in contact with water
This ash deposit is called a tuff breccia
The crater formed by these explosions is called a maar
A volcanic province will have a few maars where wet sediments are located

Surtseyan Eruptions

Surtseyan eruptions are when volcanoes spew out magma into a shallow body of water
They are very similar to phreatomagmatic eruptions, but these ones contain higher quantities of water involved
Basaltic lava is fragmented into small grains of ash due the explosion created
This creates large ash deposits
An example of this was the 2015 Tonga eruption creating an Island out of ash and scoria (An ash based rock)
The island was later destroyed by another eruption in 2022

Pelean Eruptions

A Pelean eruption is a type of volcanic eruption that creates a pyroclastic flow that flows down the slope of a volcano
A pyroclastic flow is a mixture of hot gasses and ash
They are very dangerous
They are caused by very silica rich and volatile magmas
An example of a Pelean eruption is the eruption of Mt Pelée (hence the name)
Mt Pelée is a volcano on the island of Martinique in the Caribbean located above on the edge of a subduction zone
In 1902 a massive pelean eruption occurred
In only 2 minutes pyroclastic flows reached the city of St Pierre and killed 28 thousand people
A man locked in an underground windowless jail was one of only 3 known survivors

Plinian/Vesuvian Eruptions

Plinian or Vesuvian Eruptions are a very explosive type of volcanism that produces a large column of ash which spreads across the tropopause and then collapses forming pyroclastic flows like a Pelean eruption

This requires a very felsic silica rich composition of magma that takes its time absorbing the rocks as it rises making it thick and trapping gasses within it

Plinian Eruptions are named after Pliny the Younger who gave a detailed recording of such even at Mt Vesuvius

The best example of a Plinian eruption is the eruption of Mt Vesuvius

Mt Vesuvius is a stratovolcano which famously destroyed the roman city of Pompei and Herculaneum in AD 79 by erupting and burying it under ashes

Large pyroclastic flows destroyed much of Mt Vesuvius in the process of eruption

It erupted with ~4-5 on the VEI

People were buried in hot ashes and killed instantly

Casts were made and plater was poured into the tuff to preserve their positions.

The casts are some of the creepiest things I have ever seen in my life

Ultra-Plinian eruptions/Super-volcanoes

Very large Plinian eruptions are associated with subductions zones

The collapse of a magma chamber creates a reaction that makes all of a volcano's lava erupt all at the same time as a giant ash cloud and explosion

This explosion is very energetic and creates a giant crater called a caldera

For context of the destructiveness of these volcanoes when Mt Toba erupted it almost wiped out humanity

The Moons Volcanism

The moon contains geological features called Maria

The maria are large, dark, basaltic plains on the moon formed by extremely fluid basaltic lava flowing into ancient impact basins.

They feature all kinds of volcanic and geological features such as lava tubes, domes, ridges and faults

They cover around 16% of the moon's surface

They are called Maria as that is the Latin word for seas (the first astronomers mistook the dark spots for seas)

This is why areas on the moon are called The Sea of Tranquillity or Mare Tranquillitatis in Latin

The moon also contains small cones formed by eruptions flowing out

Io's Volcanism

Io is one of the moons of Jupiter

You can always tell a moon of Jupiter if it is an affair he had in a myth

It is a very volcanically active planet

It has lavas that are composed of sulphur

It has large shield volcanoes due to its basaltic lava, which also cause large gas plumes to escape

These plumes can rise up to 500km into space

It may have a somewhat molten magma ocean inside of it

Enceladus's Volcanism

Enceladus is a moon of Saturn

It has a large thick crust made of ice

It has a very high amount of active cryovolcanism

Cryovolcanism is when ice melts into water lava flows

It has this volcanism as heat is generated by tidal forces
It has Geysers that shoot out water vapor
This water vapor contains hydrocarbons
This means Enceladus oceans could contain life
Enceladus is named after one of the giants that fought in the gigantomachy against the Greek gods. He was the giant of earthquakes and volcanoes.

The Earth's Atmosphere and Climate

Our Current atmosphere

Our atmosphere extends from the surface to around 10,000km from the surface of the earth
It is divided into 5 main layers, the troposphere, the stratosphere, the mesosphere, the thermosphere and the exosphere
The around 80% of the atmosphere is located within the troposphere as it gets thinner the further out you go
The troposphere is the layer that is where weather happens
The stratosphere is separated into many different layers (strata) of gasses and contains the ozone layers protecting us from UV radiation
The mesosphere is the layer where extraterrestrial dust particles burn up on entry
The thermosphere is the layer were charges particles form auroras
The atmosphere is composed of air, which is a mix of 78% nitrogen, 21% oxygen, 0.9% argon and around 412ppm CO_2 (0.04%).
The modern atmosphere has a layered structure characterised by changes in temperature and composition, this includes the troposphere, stratosphere, mesosphere, and thermosphere

Earth Nullschool

- https://earth.nullschool.net/
- Earth Nullschool is an interactive globe that displays real-time or past atmospheric and oceanic currents
- It is useful for studying geology and the environment as it helps visualise processes like climate change, the hydrosphere, cryosphere, and Earth's atmosphere.

The Troposphere

The troposphere is the first layer of the atmosphere
This is where all weather occurs due to it being the only layer with convection.
It makes up 75% of the planet's atmosphere
It is spread from 0 Km to 7/20 Km
The temperature ranges from the average surface temperature to around -55c at the top.
Light from the sun passes through the atmosphere it does not heat it
The surface of the earth absorbs some of the light heating it
The warm earth then transmits this heat into the troposphere warming it from the bottom up

The Stratosphere

The Stratosphere is the 2nd sphere
It is called this due to its 'strata' or layered structure
This layered structure is divided by composition and temperature
This layer contains the ozone layer that protects the earth from UV radiation
The temperature goes from -55c to -3c the higher you go due to its heating from the radiation

It is between 7/20 Km at the bottom and 50km at the top
The ozone present in the stratosphere absorbs UV radiation.
The absorption of this highest at the top heats the stratosphere from the top down

The Mesosphere

It is the 3rd layer of the atmosphere
There is little known about it as there is no way to study it due to the composition not allowing aircraft to fly there
This is the layer that asteroids burn up in when they enter the atmosphere
For this reason, it contains trace particles of dust and metal
Temp decreases with altitude from -3 at the base to -143 at the top
It is 50 Km to 85 Km

The Thermosphere

It is the 4th layer of the atmosphere
This layer absorbs all large ionizing radiation such as X-Ray
The temperature is -143 at the base and reaches up to 2000c at the top
However, there is so little there that there are that there are no partials to hit
It goes from 500/1000km
It is called ionosphere as absorbs ionizing radiation.

The evolution of our atmosphere

The composition of earth's atmosphere has change throughout time just like the surface
This change is recorded into rocks and fossils
When first formed the earths primitive atmosphere contained more water, carbon dioxide and methane
This was due to the outgassing process after formation
Carbon dioxide eventually decreased as it got trapped within rocks
Oxygen was added into our atmosphere around 2.5Ga in the great oxidation event

There are Several distinct stages in our planet's atmosphere
The formation of the earth
The Primordial Atmosphere (Haden Eon)
2nd Atmosphere (Archean Eon)
3rd Atmosphere (Proterozoic Eon)
Modern Atmosphere (Phanerozoic Eon)

The formation of earth (pre 4.5Ga)

As the Earth accreted from the planetary nebula, it trapped gasses.
These gasses were largely hydrogen, helium, methane, water and minor traces of other gasses.
The solar wind bearing down on the earth at this time would have "photoevaporated" the lighter gasses like hydrogen and helium, who reach escape velocity more easily.
At the very high heat all water evaporates and the earth is molten

Haden Atmosphere (4.5-3.8Ga)

Hydrogen and Helium are rapidly leaving the atmosphere as they "photo-evaporated".
The remaining atmosphere is heavy and rich in CO_2, H_2O and NH_3, early oceans formed under high pressure.
CO_2 decreased as it dissolved in oceans and was removed by subduction into mantle.
Formed the core of the earth
The late heavy bombardment adds water vapor

Archean Atmosphere (3.8-2.5Ga)

As earth cooled, water condensed (H_2O removed from atmosphere) and formed oceans.
Carbonate minerals (carbon dioxide combining with calcium and magnesium) were also forming in oceans, removing CO_2.
Single celled life evolves
These oceans dissolved more NH_3 forming compounds that were necessary for the formation of life, which occurred around 3.5 billion years ago.
Photosynthesizing life forms (cyanobacteria) evolved ~2.4-5 billion years ago. They started reducing the amount of CO_2 in the atmosphere and creating Oxygen.
Initially, the oxygen the cyanobacteria produced combined with iron in the oceans forming iron oxides.
This period is known as the great oxidation event, and it changed the planet entirely.

Protozoic atmosphere (2.5Ga-540Ma)

Oxygen accumulates as the iron oxygen sink was depleted, letting oxygen build up in the atmosphere.
This leads to free O_2
This decreases the greenhouse effect and causes an ice-age due to lower greenhouse gasses
Aerobic singular celled organisms evolve
Mitochondria was formed by endosymbiosis (cell eats other cell then work together), this allows for the formation of multicellular life.
The first multicellular life forms during the Ediacaran period. (see above)
Ozone forms protecting the new multicellular life from UV radiation

Phanerozoic atmosphere (540Ma – Now)

CO_2 Increases leading to a warmer earth with less oxygen, did not Favor Ediacaran fauna so they die off.
Cambrian explosion (radiation) they evolve animals with solid structures and more complex body parts.

Oxygen levels increased to around 30% as the Earth was covered with vegetation.
High concentrations of oxygen allowed large animals to develop. Huge fires in the oxygen rich atmosphere were a problem.
Vegetation the world over grew huge amounts during this period as life flourished.
A large proportion of the worlds coal and oil was formed during this time as huge amounts of biomass were developed.
A surge in volcanic activity and the production of gas and dust clouds at this time caused most of Earth's life to go extinct, killing off 90% of oceanic species, and 70% of terrestrial species.
This event resulted in O_2 concentrations dropping to 12% and carbon dioxide increasing again.
After the Permian Triassic mass extinction, O_2 increased again and has been between 18 and 23% for the last 100 million years.
It is during this period that dinosaurs evolved and went extinct, and the age of mammals and man began.

Air pressure and temperature

The temperature in the atmosphere varies
Only 12% of this heating energy is from direct sunlight
Most of it comes from infrared radiation that is emitted by the earth due to absorbing solar radiation
This infrared radiation is trapped by greenhouse gasses

Water and ash clouds rise and hit the edge of the tropopause and spread out due to the inversion of temperature
The air in the troposphere convects around
At 10km the pressure of the atmosphere is 25% that of sea level and around -50C
All of this happens because when you lower the temperature of a molecule it will move slower, the slower it moves the less pressure it exerts
The higher up you get the colder it gets as there is less radiation from the earth

Weather

Weather is the short term atmospheric conditions in the troposphere at a given place

Winds

Winds are created by pressure gradients between different locations
This happens as hot air rises upwards meaning a high pressure zone suddenly has a drop in pressure
This drop in pressure creates convection causing cold air to rush in and take its place
Pressure can be represented in isobars
This effect happens on a complex global scale moving hot air from the equators to the poles causing atmospheric convection
Perth is the 3rd windiest city in the world due to its proximity to the darling ranges
The air rising in the city causes wind to flow down the hills and accelerate as it rushes down the hills into the city, this phenomenon is called downslope winds

Air Mass and fronts

An air mass is a large pocket of air that all shares similar temperature and humidity levels within it
When these two air masses collide due to the convection it is called a front
When a cold front happens the hot air and humidity rapidly rises leading to heavy precipitation
When a hot front happens the warm air ramps slowly over the cold air forming cloud cover with steady precipitation

Clouds and rain

A cloud is a region of air that is saturated with water
This water forms in microscopic droplets or ice crystals
Clouds develop when the air that contains this water is cooled below the saturation temperature for the water
This means that the air cannot hold the water anymore and clouds are formed
Different types of clouds will reflect different conditions in a region

Atmospheric Circulation

Atmospheric circulation is caused by different parts of the world being heated differently to the others creating convections
This can be caused by the thermal gradient.
The thermal gradient is caused by the fact that sunlight that the amount of light that hits the centre of the earth but the curvature of the earths meaning higher latitudes have more area and less radiation compared to the equator.
Snow, ice and clouds have high albedo, and the ocean and rocks have low albedo.
At latitudes higher than 40 degrees there is more outgoing radiation than ingoing radiation.
The atmospheric convention makes sure that the temperature is moderated around the world

Atmospheric Cells

Warm air rises, creating low pressure zones.

Clouds form as the warm air rises and cools
Cool air descends, forming high pressure zones.
This creates a convection cell in the atmosphere.
There are 3 main cells in the atmosphere either side of the equator.
The Hadley cells, the Ferrel cells and the polar cells.
These cells cause the biomes to be created due to the convention of air and moisture

Hadley cells:

- Warm air rises at the Equator, creating low pressure and heavy rainfall. This air then moves towards the poles at high altitudes, cools down, and sinks around 30° latitude, creating high-pressure zones and dry conditions
- The air is warm air circulating from the 0° towards the 30° and rising to circulate back to the 0°
- Gives Cold to the warm areas
- This forms Trade Winds

Ferrel Cells:

- The Ferrel cell is created by the Warm air from the area at the edge of the Hadley cell towards the Polar cell which pushes the cold air from the area at the Polar cell to the area at the Handley Cell
- The air is warm air circulating from the 30° towards the 60° and rising to circulate back to the 30°
- Gives warmth to the cold areas

Polar Cells:

- Cold air descends at the poles, creating high-pressure zones. This air then moves towards lower latitudes, where it meets the warmer air from the Ferrel cell, rises, and returns to the poles at higher altitudes.
- The air is all cold, and it circulates from 60° to 90°

Storms and cyclones

A thunderstorm is a weather formation similar to cumulonimbus clouds
The air is cooled at the top of the cloud formation and precipitation and cold air start to fall while hot air continues to rise
The precipitation of these clouds are heavy rainfall and hail
The friction of these particles in the clouds cause static charging creating lighting
Lightning can heat the air up to around 30,000 degrees and can melt rocks forming fulgurites (sometimes called lightning fossils)
Around 10 people are killed by lightning every year in Australia alone
A cyclone is a thunderstorm that is formed above the ocean
The ocean acts as an endless supply of warm moist air that rotates around a centre of low atmospheric pressure
The wind speed can range from 120km to 250km per hour
This creates huge winds, waves, water surges and floods
An example of a cyclone is cyclone Yasi
This cyclone originated near Fiji and hit Queensland in 2011
It was a category 5 cyclone that hit the coast with wind speeds up to 300km/h and waves up to 10m
There was only 1 death, but the damages cost around 3.5 billion dollars
The town of Tully was completely destroyed by winds and flooding

The Noongar seasons

The seasons created by Aboriginals work a lot better for Australia then those created for Europe that were brough here
Birak: 1st summer (Dec – Jan) dry and hot
Bunuru: 2nd summer (Feb – March) hottest part of the year
Djeran: Autumn (April – May) beginning of cooler weather
Makuru: Winter (June – Jul) coldest and wettest season
Djilba: 1st spring (Aug – Sep) wet days with increasing number of clear, cold nights and warm days
Kambarang: 2nd spring (Oct – Nov) longer dry periods

Climate

Climate is defined as the long term behaviour of the atmosphere over a long period of time

What causes variation in climate

The climate is caused due to a large array of different factors
This means climatology is a very complex science with a large amount of feedback loops
Climate is mainly influenced by:
Latitude, which determines the amount of solar energy gained
Elevation, which controls the average air temperature and pressure
Position in a convention cell, which controls the average rain and temperature
Proximity to water bodies, which controls the moisture and the heating and cooling of a landmass
Proximity to warm or cold currents, which builds upon what was stated above
Proximity to mountains, which disrupt and redirect airflow
Proximity to stationary air mass

Climate types

There are a majority of different types of climates, some of the larger categories include:
Tropical climates, which are hot an humid with abundant rains throughout the year.
Dry climates, these are climates that hot and dry with little to no rain
Moderate climates are climates that are warm and have moist air for most of the year
Continental climates are climates that contain humic continental forests and sub artic climates
Polar and Alpine climates are those with no summer and very cold winters which contain permafrost

The convection currents and the resulting climate belts are essential for distributing heat and moisture around the Earth, influencing global weather patterns and ecosystems.

Equatorial Climate Belt

- It is located around the Equator where the intense solar heating at the Equator causes warm, moist air to rise, creating a low-pressure zone.
- As the air rises, it cools and releases its moisture as heavy rainfall, leading to the lush, tropical rainforests found in this region.

Desert Climate Belt

- This is located around 30° latitude, both north and south where the air that rises at the Equator moves towards the poles and descends around 30° latitude.
- This descending air is dry because it has lost its moisture over the Equator.
- As it descends, it creates high-pressure zones and arid conditions, leading to the formation of deserts like the Sahara and the Australian Outback.

Mid-Latitude Climate Belt

- This is located between 30° and 60° latitude

- In this region, the Ferrel cells dominate. Air moves towards the poles near the surface and rises around 60° latitude where it meets the Polar cell.
- This interaction creates a mix of weather patterns, including temperate climates with distinct seasons.

Polar Climate Belt

- This is located around the poles (60° to 90° latitude).
- Cold air descends at the poles, creating high-pressure zones. This air moves towards lower latitudes, where it meets the warmer air from the mid-latitudes, rises, and returns to the poles at higher altitudes.
- This results in cold, dry conditions typical of polar deserts.

Paleoclimates

Paleoclimate is the climate of the past area
We can see the paleoclimate through instrumental, historical and paleoclimate records
We have instrumental record data of the past 100-200 years or so with the creation of barometers and thermometers
We have historical records of climates that have been passed down through writing and oral accounts
E.g. there are rock paintings of hippos in the Sahara desert
We also have the Paleoclimate record
The paleoclimatic record is the record of a climate created by natural systems that we can use to calculate past temperatures
There are many different methods of dining the paleoclimate such as sediments, ice cores, rocks and fossils

Oxygen isotopes

One method of finding the past temperatures is oxygen isotopes
A normal oxygen atom (^{16}**O**) has 8 protons and 8 neutrons
There is a rare isotope of oxygen that contains 10 neutrons and is heavier
Mass fractionation means that it is easier to move and evaporate lighter atoms over heavier ones
Water is stored in ice keeping a record of the ^{16}O to ^{18}O difference
During hotter times the water is receiving more heat energy and so it can evaporate more heavy water

The most common form of oxygen has an atomic mass of 16 (^{16}O). A heavier oxygen isotope with a mass of 18 is also stable (^{18}O). The distribution of these isotopes in the environment changes as a result of changing temperature. ^{16}O is 10% lighter than ^{18}O.
During Cold Periods:

- During Cold or Glacial) Periods the oceans have a higher concentration of ^{18}O due to the colder air's inability to hold heavy water molecules.
- This means that ice has a lower concentration of ^{18}O and as ^{16}O evaporates more easily, it falls as snow, and becomes trapped in ice.
- Marine sediments will contain higher ^{18}O concentrations in marine organisms' calcium carbonate shells and limestone, due to the higher ^{18}O levels in ocean water.
- Ice cores will find lower ^{18}O concentration, indicating a cold period.

During Warm Periods:

- During Warm or Interglacial periods the oceans have lower concentrations of ^{18}O because warm air can evaporate and retain more ^{18}O molecules.
- This means that Ice with have a higher concentration of ^{18}O as it is more common in precipitation that falls as snow and gets trapped in ice.

- Due to the reduction of ^{18}O in the ocean the concentration of it in calcium carbonate shells and limestone will be lower
- Ice cores will have higher ^{18}O concentrations

Using this information we can track the ^{18}O records in these places to find whether there has been an Interglacial period or not

Ice Core Data as a record of past climate

Ice cores are drilled from deep ice caps on land.
The deeper the ice, the older it is, the further back in time it was formed.
Records can extend for hundreds of thousands of years with kms of core meaning they can go back around 800,000 years
This happens as snow compacts with new layers deposited on top, it forms ice with tiny bubbles of atmospheric gas trapped in between.
These gasses can include:

- Oxygen isotopes – This can be used with both 18O and Deuterium
- CO_2 – Shows Carbon Dioxide PPM
- CH4 – Shows Methane PPM
- Other gasses such as aerosol

CO_2 and methane in ice cores show correlations with climate change and concentrations

- When CO_2 is higher then temperature is higher
- When methane is higher then temperature is higher

Ice cores show oxygen isotopes such as Delta D (deuterium) and Delta O (oxygen-18)
They correlate with temperature:

- Delta D: Higher values indicate colder periods.
- Delta O: Higher values reflects colder climates.
- These ratios result from changes in precipitation patterns influenced by temperature and atmospheric circulation.
- Evaporation from the ocean leaves behind lighter isotopes (like oxygen-16).
- As water condenses into snow or ice, heavier isotopes (like oxygen-18) preferentially fall out.
- Thus, isotopic composition reflects the temperature at the time of precipitation

The Vostok Ice Core Record

- The Vostok Ice Core is a record of Earth's climate derived from ice drilled at the Soviet Vostok Station in Antarctica.
- The ice core provides data going back approximately 420,000 years.
- The Vostok record shows cyclical patterns in Earth's climate, particularly the alternation between glacial (cold) and interglacial (warm) periods.
- It shows the relationship between atmospheric concentrations of greenhouse gases (CO_2 and CH4) and temperature. Higher levels of these gases correlate with warmer periods.
- The record indicates that current CO_2 levels are significantly higher than at any point in the past 420,000 years.
- Temperature data from the ice core shows that Earth's climate has varied significantly, with temperatures in the past sometimes being much colder or warmer than today.
- The Vostok data shows how Earth's climate has naturally changed over millennia

The Exxon Sea Level Arc

- The Exxon Sea Level Arc is a global sea level curve developed by Exxon geologists in the 1970s and 1980s.

- This curve maps changes in global sea level over the past 250 million years, based on geological and stratigraphic data.
- It is one of the first comprehensive reconstructions of sea level history on a global scale.
- The curve reveals shows fluctuations in global sea levels, correlating with major geological and climatic events.
- The Exxon Sea Level Arc shows how climate cycles, including glaciations and warm periods, have influenced sea levels over millions of years.
- It provides evidence for long-term natural climate trends, helping to understand how the Earth's climate system operates on geological timescales.

Sediment cores and fossils as a record of past climate

Fossil plants serve as important indicators of the climate that existed when they were alive.
Palaeontologists base their assumptions on the principle of uniformitarianism, which posits that the ecological and climatic requirements of fossil plants were similar to those of their modern relatives.
This means that if a fossil plant resembles a plant that currently thrives in warm, humid climates, palaeontologists might infer that the ancient environment was similarly warm and humid.
This method relies on comparing the characteristics of fossil plants with those of contemporary species to draw conclusions about past climates.
An example of this is leaves:

- Leaf shape and margin type are critical features in determining the climate conditions under which fossil plants lived.
- Leaves with smooth, entire margins are typically associated with warmer and wetter climates, whereas toothed leaves are more common in cooler and drier environments.
- The analysis of leaf margins, known as leaf margin analysis, allows scientists to infer past climate conditions.
- For example, a fossil leaf from an arid climate might have more pronounced teeth or serrations, while a leaf from a tropical climate would likely have a smoother, entire margin, reflecting the different environmental conditions where these plants once existed.

The ratio of oxygen isotopes, particularly Delta 18O to Delta 16O, in the calcium carbonate of marine organism shells, is a key method for determining the temperature of the water in which these organisms formed their shells.
This ratio changes with temperature; a higher ratio of Delta 18O generally indicates cooler water temperatures and more extensive ice coverage.
An example of this is Foraminifera:

- Foraminifera are microscopic marine organisms with calcium carbonate shells that serve as useful indicators of past climate change.
- The oxygen isotope ratios preserved in their shells reflect the temperature and composition of the seawater in which they lived.
- By analysing these ratios in sediment cores, scientists can reconstruct past ocean temperatures and infer global climate conditions at different points in Earth's history.
- This makes foraminifera crucial to understanding the Earth's climatic past and predicting future climate trends.

Pollen grains as a record of past climate change

Pollen grains are microscopic reproductive organs of plants.
They are generally dispersed by wind.
Each species has its own unique morphology, and hence they can be identified.
Existing species of plants are adapted to particular climate zones.

E.g. alpine plants can only survive in cooler wet climates such as those found more commonly during interglacial periods, whereas tropical plants need warm, rainfall rich climates similar to those commonly found in glacial periods.
Pollen grains are easily preserved in fine sediments of lakes where fine sediments accumulate.
If we assume the species that existed in the past are similar to species existing today in their climate preferences, fossil pollen grains can be used to infer temperature and rainfall of the region when the plant existed.
Pollen can assist palaeoclimatologists to determine climate changes back millions of years ago.

Anthropological records of climate

Humans have always had a record of the past climate, ever since the first civilisations.
This can be seen through things such as human migration and habitation
Human dispersal from Africa is thought to have occurred by migration over land bridges that connected continents and island during glacial period due to the lowering of sea level.
Archeologically evidence from stone tools and fishing blades indicate that the first North Americans followed a coastal route from Asia to North America.
Many indigenous cultures preserve oral histories, including cultural memories of climate change.
These can include periods of sea level change, changes in ecotypes due to rainfall and even memories of significant places that are now underwater
Many archaeological sites are likely to be submerged as sea levels rose during the last interglacial period some 10 -12,000 years ago.

This is caused by:

- Glacial periods cause a reduction of sea level.
- Ice sheets grow and thicken accumulating water
- Reduced sea levels change ocean levels around continents and change the heat flow from the equator to the poles.
- In certain areas rainfall and temperature decreases and tropical ecosystems gradually change to temperate and dessert ecosystems.
- Humans evolved about 3 million years ago. Glacial and interglacial periods occur on an approximately 100,000 year oscillation.
- Human have had to move and culturally adapt to the changing climate.
- Their tools - (cultural artefacts) and bones have been preserved as fossils and archaeological remains.
- Cultural artefacts can indicate human occupation in areas that no longer support human populations.
- This indicates the past climate change

Fossil landscapes

When a fluvial landscape undergoes glaciation, significant changes occur in its topography and physical features.

- Initially, the river valleys, which are typically V-shaped due to the erosive action of flowing water, become U-shaped as glaciers carve through them.
- The weight and movement of the ice erode the valley sides and floor, creating a broader, flatter, and more uniform cross-section.
- Additionally, the landscape becomes dotted with features like cirques, arêtes, and horns, formed by the intense erosive power of the glacier.
- As the glacier advances, it scours the land, carrying with it large amounts of debris, which are then deposited as the glacier recedes, leaving behind moraines, drumlins, and other depositional features.

When glacial recession occurs, the landscape experiences further transformation.

- As the ice melts and retreats, the previously glaciated valleys are often left with deep, over-deepened troughs that may fill with water, forming ribbon lakes or tarns.
- The landscape also features extensive moraines, which are accumulations of debris deposited at the edges and terminus of the glacier.
- These moraines mark the furthest advance of the glacier and are indicative of its former size and extent.
- The retreat of the glacier often results in the formation of outwash plains, composed of sediments that are carried away from the glacier by meltwater.

A sequence of terminal glacial moraines provides valuable evidence of past climate change.

- Each terminal moraine represents a position where the glacier paused during its advance or retreat, allowing for the accumulation of debris at its terminus.
- The presence of multiple moraines in a sequence indicates periods of stability or slight advance, followed by retreat, reflecting changes in the climate over time.
- These moraines can be used to trace the history of glacial movement, showing patterns of cooling and warming.
- The study of these features allows scientists to reconstruct past climate fluctuations, providing insights into how climate has changed over time and the impact of these changes on the landscape.

Paleoclimates and temperatures

Throughout the history of the earth the climate has been constantly changing and evolving
This can be through changes in the planets orbit called Milankovitch Cycles or the plate tectonics Supercycle
If we learn and understand the climates of the past we can understand present climate change better
An example of a past climate is the Paleocene-Eocene Thermal Maximum where it was so hot that there was no ice cap at all, the sea level was 100-200m higher than it was today

Milankovitch cycles

Milankovitch cycles are a set of predictable variations in the Earth's orbit around the Sun, named after the Serbian scientist Milutin Milankovitch.
He discovered them under house arrest
These cycles are considered one of the key factors influencing long-term climate change on our planet.
There are three main Milankovitch cycles:

Eccentricity:

- This cycle involves changes in the Earth's orbit from nearly circular to more elliptical over a period of about 100,000 years. The degree of eccentricity affects the amount of solar radiation received by the Earth. When the orbit is more elliptical, there are variations in the distance between the Earth and the Sun, leading to differences in solar energy received at different times.

Obliquity:

- Obliquity refers to changes in the tilt of the Earth's axis, which oscillates between approximately 22.1 and 24.5 degrees over a cycle lasting around 41,000 years. The tilt affects the distribution of solar radiation across the planet's surface. A higher tilt means more

extreme seasonal variations, while a lower tilt results in milder seasons.

Precession:

- Precession refers to the wobbling motion of the Earth's axis, which completes a full cycle over approximately 26,000 years. This motion causes the orientation of the Earth's axis to shift relative to the stars. The precession cycle affects the timing of the seasons. For example, when the Northern Hemisphere experiences summer, it can occur when the Earth is closer to or farther away from the Sun, depending on the stage of precession.

These Milankovitch cycles can have significant impacts on past climate over long timescales.
The combined effects of eccentricity, obliquity, and precession influence the intensity and distribution of solar radiation received by the Earth's surface.
These changes in solar forcing can result in alterations in the amount and spatial distribution of energy available for heating the atmosphere, oceans, and land surfaces.
The Milankovitch cycles alone do not cause abrupt climate changes, but they act as the pace-maker for natural climate variability.
They provide a framework that helps explain the timing of ice ages and interglacial periods in Earth's history.
By studying the geological and ice core records, climate scientists have observed correlations between the variations in these cycles and past climatic changes.
It's important to note that while Milankovitch cycles are natural drivers of long-term climate change, they interact with other factors such as greenhouse gas concentrations, volcanic activity, the plate tectonic super cycle and other feedback mechanisms within the Earth's climate system.

Cycle Simulator:
https://cimss.ssec.wisc.edu/wxfest/Milankovitch/earthorbit.html

Plate Tectonics Super Cycle

The plate tectonics Supercycle refers to a long-term cycle of geological processes involving the movement and interaction of Earth's tectonic plates over hundreds of millions of years.
It describes the continuous cycle of supercontinent formation, breakup, and reformation.
The most well-known supercontinent is Pangaea, which existed around 300 million years ago.
The Supercycle consists of the following stages:

1. Supercontinent is present and the large continent is trapping and accumulating heat underneath.
2. Bulging and sagging of the supercontinent as the build-up of heat causes it to become unstable.
3. Rifting of supercontinent occurs and separate continents form with new ocean basins between due to seafloor spreading. As the plates move apart, magma rises from the mantle to form new oceanic crust
4. Rapid sea floor spreading and continental drift occurs, formation of mid ocean ridges, which widens the oceans, and subduction zones, which destroy old oceanic crust and create volcanic arcs.
5. Supercontinent Assembly occurs as subduction zones bring continents back together. The process slows as heat built up in stage 1 has been released and eventually subduction stops, this then reverts to stage 1

This cycle has various impacts on the global climate:

- Volcanism: The breakup and continental drift phases correspond with higher volcanic activity, and therefore an increase in atmospheric CO_2 or Conversely, the lack of volcanism during supercontinent formation phases tends to lower atmospheric CO_2

- Weathering and mountain building: The collision and assembly phase results in the uplift and weathering of rock, which consumes CO_2 and lowers the atmospheric concentration of the gas. Less mountain building occurs during breakup and drift phases however.
- Ocean circulation and ice sheets: Supercontinent assembly cuts off ocean circulation and heat transport to the interiors of continents. This favours the formation of continental ice sheets which have a high albedo, reflecting more sunlight and tending toward global cooling. Conversely, breaking up supercontinents allows more widespread circulation of oceans and heat transport, preventing or reversing the growth of continental ice sheets.
- Sea level: Supercontinent formation closes shallow ocean basis and forms larger deep oceans, which has the effect of lowering sea level, an effect reinforced by the formation of land ice. Conversely, the breakup of supercontinents creates more shallow oceans and raises sea level.

The Permian-Triassic extinction (Repeat)

This extinction event killed over 95% of marine and 70% of terrestrial species.
It lasted a few hundred thousand years.
It is also called the Great Dying
It set the stage for the archosaurs and dinosaurs
Trilobites are gone =(
It was caused by the eruption of the Siberian traps, which created shifts in temperature and environmental conditions.

<u>Impact of a meteorite</u>

Shack quartz has been found in global sediments.
Suddenness would explain why organisms did not evolve to cope with change
May have caused subsequent volcanism which causes all bad things
The opening of the Siberian traps large basalt floodplain which covered two million square kilometres of earth surface
This would have caused caid rain and dark clouds
Methane is 40 times stronger a greenhouse gas than CO_2
Releasing a lot of methane from Siberian permafrost would have rapidly accelerated.
The reduction of oxygen in the ocean due to warmer temperatures allowed surface reducing bacteria to flourish
A collection of all of the above perhaps except a meteorite impact through this may have been the trigger to the volcanism
The Siberian traps open
Tons of CO_2 is released from them, coal deposits are ignited, forests burn.
Ash and acid rain kill plant life and marine ecosystem
This heating shutdown the thermohaline circulation, this causes anoxic oceans.
Methane and hydrogen sulphides if formed in the ocean.
Everything dies (70% of all life and 90% of all marine life)
It is also called the Great dying

The last ice age

The last glacial maximum happened between 25 and 16ka with its peak occurring around 21ka
The global temperature average was only 2°C colder than today's average.
The sea level was 125m lower than today
The continents were 20% larger
Australia was more arid, cold and windy with little monsoons

Major Shifts In The Earths Climate

PETM (Palaeocene–Eocene Thermal Maximum) - ~56 million years ago

- The PETM was marked by a rapid global temperature increase of about 5–8°C over just a few thousand years.
- This warming was driven by a sudden injection of carbon into the atmosphere and oceans—most likely from massive volcanic activity in the North Atlantic Igneous Province.
- This volcanism may have destabilised methane hydrates on the seafloor, releasing even more greenhouse gases.
- Ocean acidification followed, devastating deep-sea benthic foraminifera.
- Terrestrial ecosystems experienced migrations and extinctions, and mammals rapidly evolved, including the first appearance of modern groups like primates.

EECO (Early Eocene Climatic Optimum) - ~53 to 49 million years ago

- This was one of the warmest sustained periods in Earth's Cenozoic history, with polar regions largely ice-free and tropical conditions extending far into the higher latitudes.
- The warmth was maintained by elevated CO_2 levels, likely driven by ongoing volcanic emissions from regions like the North Atlantic Igneous Province and Ethiopian Traps.
- Warm oceans experienced stratification and reduced deep-ocean circulation.
- Coral reefs thrived, biodiversity increased, and there were significant evolutionary advances in both marine and terrestrial life.

LEC (Late Eocene Cooling) - ~38 to 34 million years ago

- A gradual cooling trend began as volcanic CO_2 emissions declined and silicate weathering on uplifting mountain chains drew down atmospheric CO_2.
- At the same time, the continents continued to drift, altering ocean currents and reducing poleward heat transport.
- This shift began to build permanent ice on Antarctica.
- The biosphere responded with evolutionary pressures leading to adaptations to cooler, drier environments, such as the emergence of grasslands and expansion of more cold-tolerant species.

EOT (Eocene–Oligocene Transition) - ~34 million years ago

- This marked the first major glaciation of Antarctica and one of the most dramatic climate shifts in Earth's history.
- It involved a sharp drop in CO_2 levels (possibly below 600 ppm) and the opening of the Drake Passage and Tasman Gateway.
- These tectonic changes enabled the formation of the Antarctic Circumpolar Current, thermally isolating the continent.
- Milankovitch cycles (changes in Earth's orbit and axial tilt) triggered glaciation, while feedback loops like ice-albedo amplified it.
- This caused a sea-level drop and widespread extinction of warm-adapted marine species.

MMCO (Middle Miocene Climatic Optimum) - ~17 to 14.5 million years ago

- Global temperatures rose again, reaching around 3–6°C above pre-industrial levels.
- This warming is linked to increased volcanic activity and tectonic uplift in areas like the Himalayas, which released large volumes of CO_2.
- High atmospheric CO_2 levels led to reduced polar ice and expanded subtropical climates.
- Ice sheets on Antarctica briefly retreated.
- This period also saw significant evolutionary diversification in mammals and expansion of warm-adapted flora.

MMCT (Middle Miocene Climate Transition) - ~14 to 13 million years ago

- A relatively rapid global cooling event, the MMCT followed the MMCO.
- As volcanic CO_2 emissions decreased and silicate weathering intensified, atmospheric CO_2 dropped.
- The Antarctic ice sheet expanded further and became more stable.
- Oceanic circulation also changed, promoting deep water formation and heat loss.
- The increased ice cover reinforced the cooling through the ice-albedo feedback loop.
- Grasslands spread widely, favouring the evolution of grazing mammals.

PG (Pliocene Glaciation) – ~3.3 to 2.5 million years ago

- Although CO_2 levels remained relatively high (~300–400 ppm), gradual cooling occurred due to orbital (Milankovitch) cycles and long-term drawdown of CO_2 by weathering and biological sequestration.
- The Panama Isthmus closed around this time, which altered ocean currents and enhanced Atlantic meridional overturning circulation, likely cooling the Arctic.
- Ice sheets grew on Greenland and Antarctica.
- These climatic shifts set the stage for the cyclical ice ages of the Quaternary period.

The Hydrosphere and the Cryosphere

The water cycle

There are 3 main phases of water during the water cycle: Solid, liquid and gas
96.5% of all of the water on the planet is located in the oceans
The rest of the water is either frozen or underground
The water cycle has 3 main steps
Liquid water evaporates into vapor, it condenses to form clouds then it precipitates back down as rain, ice or snow
Liquid water that flows on the land is called runoff
If the water flows underground, it is infiltrating and percolating the ground
The transpiration of plants also releases water vapor

Ocean water

Ocean or seawater varies depending on where it is located but on average it is made up of around 96.5% water, 1.9% chlorine, 1.1% sodium and the final 1% is composed of other elements
If all of the water on earth would disappear right now the floor of the ocean would be covered in a
The ocean water gains its chlorine anions and sodium cations from the erosion of continental rocks
The amount of sunlight and the temperature of the ocean varies depending on the depth of the ocean
The ocean has a very large heat capacity as it can absorb an immense amount of heat without warming up, which helps to regulate costal temperatures

Surface Currents

The ocean has flows within it that are called currents
Surface currents occur when wind pushes water in a certain direction
They rotate and loop around the planet due to the Coriolis effect
These looping currents are known as Gyres
There is a smaller type of gyre known as an Eddie
WA is effected by the Leeuwin current which moves N > S

Generally, currents move in a clockwise direction in the northern hemisphere and anticlockwise in the southern hemisphere
Ocean currents move heat and nutrients around the globe
Warm currents flow out from the equator and carry heat to the poles.
Cold currents from the poles move towards the equator and cool the tropics
Ocean currents have a huge impact on the temperatures and climates of adjacent land.
Air above warm currents absorb warm moisture.
Onshore winds that carry air over these cold currents blow onto warmer land but there is little evaporation so there is little moisture and therefore less rainfall.
Oceanic Gyres are large, circular currents that form in the surface of the ocean.
They are driven by the prevailing winds and move anticlockwise in the southern hemisphere and move clockwise in the northern hemisphere.
This is because of the Coriolis effect

Garbage patches =(

Garbage patches are large collections of rubbish that are found in the stable current less centre of the oceanic gyres
They can reach very large sizes with the Great Easter pacific garbage patch covering 1.6 million km_2 with around 80k tons of plastic
Contrary to popular media it is not an island made of garbage but is a accumulation of plastic, debris and chemicals (like soups with bits in)
There are cleanups underway, but it is hard to do so as the mass is constantly increasing and as stated above it is a large soup of rubbish not a solid mound
This problem can be solved by decreasing plastic waste

Deep currents

Deep currents are vertical currents where upwellings bring deep water upwards and downwelling draw surface water downwards
They occur near the coast where winds pull surface water away drawing up deep water or push water towards the coast forcing it downwards
Upwellings bring nutrients from detritus that has sunk to the sea floor back upwards and towards the surface helping the grown of plankton and fishes
These deep currents are a result of the differences in water temperature and salinity (The thermohaline circulation)
The surface of the ocean is warmer than the deep oceans, which are an Average temp of 4°C
This is because the surface oceans are heated by the sun.
The thermocline is the name for the transition from warm surface waters to cold deep waters.
This cold water is formed In the Arctic and Antarctic, the surface of the ocean can freeze, forming sea ice.
When water freezes, it leaves behind the salt.
This creates residual very cold, very salty water.
The cold salty water is very dense and sinks to the bottom of the ocean.
The salty, cold deep water formed at the poles sinks to the bottom of the ocean.
Rainwater and heating at the surface causes less dense surface water to form.
As organisms living in the surface of the ocean die, they sink into the ocean, taking nutrients with them.

At the bottom of the ocean, volcanic vents add mineral nutrients to sea water.
These factors combine to make deep ocean very nutrient rich. However, nothing grows there due to the lack of sunlight.
This deep water is upwelled due to the circulation of surface currents

Thermohaline Circulation

Ocean circulation is driven by wind waves at the surface, while temperature drives the deeper currents.
Density changes are created by variations in the temperature and salinity, this means the cooler and higher salinity means that it is more dense
Surface currents transport heat from the equator to higher latitudes.
Heat is lost and sea ice is formed.
Cooling water is high salinity and is rich in salt due to water leaving to form ice.
This sinks and forms deep water.
Cold, deep water will slowly circulate back to the equator where it will be heated again.
This cycle, driven by density and temperature, is called the Thermohaline circulation (THC) and it moved heat around the planet.

Waves

Waves are the results of wind pushing water creating ripples that build into waves
Waves do not move laterally instead the water moves up and down until it breaks on the shore du to friction
The size of the waves relate to the windspeed due to energy exchange
They are responsible for coastal erosion

Coastal Landforms

Coasts are the area of land that connects to the ocean
These areas vary largely depending on numerous factors
A beach is an accumulation of detrital sediments of quartz and carbonates
A tidal flat is a beach that is submerged during high tide and contains mud and silts
A rocky coast is made up of cliffs and fragmented rocks that are eroded away
Estuaries are where seawater floods river channels
Deltas are where sediments are deposited in a fan shape upon the coast
Organic coasts are coastlines with organic coverings such as wetlands, or reefs

The Great barrier reef

The great barrier reef is a coral reef that is 2,300km long and is made up of over 3000 reef systems
It is the largest reef in the world and makes up 1/3 of all the worlds corals
It is a UNESCO world heritage site
A reef is formed out of small coral polyps which secrete a protective cup called calyx
The barrier is formed from generations of formed corals
The reef started forming around 20Ma around the base of the Great Dividing Range when sea level rise submerged it
The current reef formed around 8ka after the last ice age
It has a vast array of biodiversity
Unfortunately, it has lost 50% of its coral since 1995 due to climate change

Streams

Running water is a stream which flows into a channel from high to low elevation
Streams capture fresh water from runoff from rain, melting snow and groundwater

Streams erode the substrate and form an network of interconnected channels
An array of streams is called a drainage network

Basins and Divides

A drainage basin is a basin where all of the water and streams drain into a common sink
Basins are usually separated by large divides caused by topographic highs
All but one of the drainage systems in Australia lead to the ocean
Lake Eyre (Kati Thanda) has its own drainage system and is the second largest drainage system in Australia
Lake Eyre is the largest salt lake in Australia and is around 144 x 77 km wide, covering around 9,000 km_2.
It is the lowest point in Australia at 17m below average sea level
It is a dry lake with a thin crust of evaporite
Every 8 or so years floodwaters from northern monsoons drain into the lake meaning it has a small flood every 3 years a large one every 10 years.
It completely fills around 4 times every century

Erosion and transport

Around 3% of a rivers energy is used in the erosion process.
It is used to remove lose sediments, break up larger rocks, and dissolve minerals
The efficiency of this erosion depends on the volume and speed of the water
These sediments are transported through saltation, traction, dissolution and suspension

Sediment deposition

When an environments energy decreases the stream cannot transport the coarser particles which get deposited causing them to be deposited as fluvial deposit
When fast flowing streams enter a larger body of water, they lose energy and sediments will be deposited
Larger flatter areas such as floodplains have very low energy and tend to deposit very small particles such as clay and silt

River flows

There are 3 different zones in a river system and its landscape
The source zone, the transition zone and the floodplain zone
The amount of energy in a river depends on the steepness of the slope it runs down
The more energy in the river the heavier the particles that the river can transport down and the more active it is in the erosion process

Porosity

Groundwater happens when water infiltrates downwards into the rocks below the surface
This water is found in the rock itself, as it contains lots of small pores
There are two types of porosity, primary and secondary
Primary pores are the empty spaces between the grains in rocks
Sandstone is up to 30% porous
Secondary pores are gaps that result from the dissolution of rocks
Permeability is how easy it is for water to flow through a rock, this depends on the connection of the pores

Aquifers

Aquifers are regions of sediments and rocks that have high porosity and permeability

Aquitars are similar but have low permeability
Some aquifers are confined by barrier of aquitars
Most of the water in an aquifer is located in the saturated zone also called the water table
Despite the name the water table is not flat but instead follows the topography of the surface
Water still flows when underground just a lot slower, anywhere from 1m-1cm a day
The rocks and sediments filter out all of the impurities within the water
They can exit into bodies of water as springs or hot springs in geothermally active areas

Perth has one of the largest aquifers in the world
There are 3 separate layers to our aquifers
The superficial layer, which is the shallowest aquifer that stretches across the coastal plain
The Leederville aquifer which is several hundred metres thick
Then the Yarragadee aquifer which is the oldest, deepest and largest aquifer which can supply water even during droughts

Frozen Water

Ice is a frozen water crystal
Its different forms behave like different rocks
Ice is a crystal like quartz
Snow is sediment like sand
Compacted snow is like a sedimentary rock
Frozen ice is an like an igneous rock
Ice caps have a large control of the climate due to their albedo
Ice makes up 70% of the earths freshwater
Glaciers form when the air is cold and there is abundant snow all year round
They move slowly down mountains transporting rocks and sediments as they erode the substratum
This forms glacial striations
Glaciers leave U-shaped valleys and deposit moraines (conglomerate and breccia)
They allow us to identify past ice age

Permafrost

Permafrost is a ground covering that contains water that has been frozen for a period of time longer than 2 years
This layer can reach several Km thick
Around ¼ of the Norther hemisphere is covered in permafrost
Permafrost can also be found on mountains regions
It contains a large amount of greenhouse gas that is stored from organic matter

Earth Resources and a sustainable planet

What are resources

Earths natural resources are the products and services that we have to use for our survival or our benefit
Some resources are reusable as they can be used again and again
Some resources are renewable as they can be replaced over a lifetime
Some resources are non renewable, once we consume them they are gone forever

Societies resource use

When humanity first evolved our early needs where only air, water and food
However today we are reliant on large quantities of material and energy

This means we need the material to build things and create energy to make them function
Most of the resources we use originate in geological material or originate from geological processes
One of the worst problems we face is that the world population is exponentially increasing, we are wasting resources and the use of resources that modify the world around us

Types of energy

There are many types of energy sources:

- Solar energy
- Gravitational energy
- Biomass energy
- Fossil fuels
- Chemical reactions
- Geothermal energy
- Nuclear energy

The usefulness of these energy sources depends on the density of the materials and the amount of infrastructure needed to extract the energy

Fossil fuels

Fossil fuels are a type of energy created from carbon and hydrocarbon chains
They can come in gas, liquids or solids
Fossil fuels are essentially nature storing the suns energy
Their state depends on the molecule lengths
Burning them provides energy but outputs a lot of CO_2 as a byproduct
The denser the hydrocarbon the more energy they produce
They are the most important source of energy used by society currently as they provide a majority of our energy and as well as their uses in other products such as cars

Coal

Coal is made up of almost pure carbon with small trance amounts of other minerals
Its formation requires the deposition of plant material in swamps or rainforests so it does not appear before 420Ma
A majority of it was deposited in the carboniferous period around 360Ma
They require an anoxic deposition environment to prevent them from being decomposed by bacteria
Once they are buried they need enough pressure and heat to compact the material and remove the water
Anthracite is the level of coal richest in carbon but it needs to be buried around 8km deep to achieve this level of metamorphism
To find coal we look for sedimentary sequences that were deposited in semitropical climates
It is excavated using strip mining or underground mining techniques
It is primarily used to generate electricity in power plates
The heat that it produces while burning is used to convert water into steam which drives a turbine producing electricity
Another type of coal is bituminous coal, this type of coal is sued to make steel
Pros:

- It Is a simple and abundant source of energy

Cons:

- It creates lots of CO_2 Pollution
- It forms acid rains
- It can sometimes result in radioactive U release 100x more than at a nuclear power plant

Coal:

- Coal starts as organic sediment called peat which contains energy from photosynthesis
- It forms in terrestrial environment
- Peat is formed of partially decomposed and preserved remains of plants
- Peat collects in swamps underwater where an oxygen poor environment preventing oxidation/decay by bacteria
- Most if the coal was formed from the carboniferous period.
- Burring the organic sediments with more sediments increases the confining pressure
- Temperature increases with depth of burial due to geothermal gradient
- Heat and pressure over time convert the organic deposits into fossil fuels
- Often sands, conglomerates, breccia, shales
- Similar to metamorphism, the more pressure and heat the more pure the coal is
- Coal behaves like any other sedimentary rock
- These layers are called coal seams and cab be easily mapped and mined
- Most of this coal was formed during the carboniferous (CARBON)

Gas and oil

Gas and oil are made up of hydrocarbon chains
These chains can be long like in oil or short like in gas
The formation of oil & gas requires a large number of dead plankton to accumulate at the bottom of an ocean
The anoxic environment at the bottom of the sea means that it is not eaten by bacteria
It needs to be covered in sediment, but not so much sediment that it loses its carbon concentration
After it is buried, the temperatures increase then pressure and lithification change the sediments in organic shale which becomes the source rock for the oil and gas
If they are at a high enough temperature they produce oil.
Any temp over 160 can produce gas
Oil will rise through the rocks until it is stopped by an impermeable cap rock
The rock that contains the oil Is called a reservoir and must be porous of the 1st or 2nd type for the oil to be extracted

A good example of a source of natural gas is the door to hell

- The door to hell is a large crater in the Karakum desert in Turkmenistan that has been burning since 1971
- The heat produced by this burning is so hot that you cannot stand on the edge of the crater
- Natural gas is constantly seeping from the hole
- It was found when local geologists were drilling for oil and gas leading to the cavern collapsing
- They lit the gas to get rid of it but its still burning 50 years later

Most natural gas reservoirs are conventional reserves meaning the gas has moved from the source rock making it easy to pump up
The improvement in technology and increase in demand has lead to the collection of gas from unconventional reserves meaning the gasses source rock itself
To find oil and gas you need to find the right layers of deposited rocks and trace the source rock and the reservoir
If there is a high chance of finding oil drilling begins
This costs tens of millions but you make back your money by selling about 30% of the reservoirs supply

Fracking is a technique that breaks up the reservoir rocks into smaller pieces allowing oil to flow more freely
The main use of oil is to power internal combustion engines, generate heat and to create a majority of plastic products

Pros:
They are the most important and critical source of fuel and plastics
Cons:
Exploration disturbs the ecosystem, it leads to chemical and physical pollution, it leads to high levels of greenhouse gas pollution

Petroleum:

- Thick layers of dead plankton(Ooze) accumulate on the sea floor
- These contain energy from photosynthesis
- The ocean floor is very oxygen poor, preventing oxidisation of the sediments
- It forms in a Marine environment
- Burring the organic sediments with more sediments increases the confining pressure
- Temperature increases with depth of burial due to geothermal gradient
- Heat and pressure over time convert the organic deposits into fossil fuels
- Often muds, limestone and sand
- Some biogenic gas formed from bacterial digestion
- Higher temps and pressure forms oil
- Very high temperatures and pressures convert all this into natural gas
- Petroleum is a fluid and can flow so it needs to be trapped to form a deposit
- The fluids are less dense and will rise through porous media to the highest point
- Impermeable Layers can trap and concentrate the petroleum

Nuclear fuels

Uranium is a naturally occurring element that is made up of 238 and 235 nucleons
It occurs within differentiated rocks (e.g. granite)
Most rocks are not rich in Uranium but instead the uranium deposit is enriched by hydrothermal fluids
This happens when the U is dissolved by hydrothermal water and concentrated into minerals like uranite
It can be leached from sediment but also reprecipitated in sedimentary sequences
Standard U238 is radioactive but U235 is radioactive and fissile
An element being fissile means that when it is hit by a neutron it will split into two lighter elements releasing a large amount of energy
Plutonium is a manmade nuclear fuel that if formed as a byproduct of the bombardment of U_2^{35}
Around 1/3 of all nuclear energy is created from Plutonium
The mining techniques used to extract plutonium are similar to techniques used for other ores
Finding the source deposit for uranium is simple as we can trace the ambient radiation of the deposit
Uranium ore can also be created as a byproduct of mining other materials
Special mining techniques and technology are needed to reduce worker radiation exposure
To be put into reactors the uranium needs to be enriched meaning it needs to have a higher concentration of 235
The naturally occurring amount is 0.71% but in need to be enriched to 5%
While the primary use of Uranium is to generate electricity there is some application of it in research
Pros:
Highest energy to density ratio of any fuel type, no constant emission or greenhouse gas emissions are created

Cons:
It produces long life radioactive waste, it has large costs to build and maintain, there are large public concerns with nuclear reactors

Summary:

- Nuclear energy uses nuclear reactions to generate heat, which is then used to produce electricity.

How the Energy is Obtained:

- Nuclear Fission: The process of splitting atomic nuclei (usually uranium or plutonium) to release a large amount of heat.

How it is Stored:

- Spent Fuel Storage: Used nuclear fuel is stored in cooling pools or dry casks to manage radioactive decay, it can be place back into other reactors to get more energy out of it
- Advanced Storage: Development of long-term storage solutions like geological repositories.

How it is Transported:

- Transmission Lines: Electricity generated from nuclear plants is fed into the grid and transported to consumers.

Pros:

- Low Greenhouse Gas Emissions: Nuclear power plants emit negligible amounts of CO_2 during operation.
- High Energy Density: Small amounts of nuclear fuel can produce large amounts of energy.
- Continuous Power Supply: Provides a stable and reliable source of base load electricity.
- Its cool

Cons:

- High Initial Costs: Construction and decommissioning of nuclear plants are very expensive.
- Radioactive Waste Disposal: Managing and storing radioactive waste poses long-term challenges.
- Risk of Nuclear Accidents: Although rare, accidents can have severe and widespread consequences

Hydropower

Hydroelectric power is power that is created by harnessing the power for flowing waters potential energy
Dams can harvest this energy by using waters kinetic energy to drive a turbine with generates electricity
Dams can also be used to collect and pump water to houses
They need a constant supply of water to work
Geologists need to evaluate local geology to understand it a dam is suitable
Most countries already have the ability to make dams
Pros:
They give clean renewable energy, no constant emissions or greenhouse gas emissions, it helps manage floods and provides water for irrigation
Cons:
They require energy to build, they have major impacts on the environment and water quality, they can displace local populations through the creation of artificial lakes

Summary:

- Hydroelectric power harnesses the kinetic energy of flowing or falling water to generate electricity, typically using dams and turbines.

How the Energy is Obtained:

- Water stored in reservoirs (dams) is released to flow through turbines, generating electricity or it utilizes the natural flow of rivers, requiring less storage and infrastructure.

How it is Stored:

- Pumped Storage Hydropower: During periods of low demand, surplus electricity is used to pump water to a higher reservoir. This water can be released to generate electricity during peak demand times.

How it is Transported:

- Transmission Lines: Electricity is transported from hydroelectric plants to the grid via high-voltage transmission lines, ensuring distribution to consumers.

Pros:

- Renewable and Clean Energy Source: Utilizes a natural and replenishable resource.
- Reliable and Stable Power Supply: Can provide base load and peak load electricity.
- Multipurpose Infrastructure: Dams can also be used for flood control, irrigation, and water supply.

Cons:

- Environmental Impact: Alters aquatic ecosystems, affecting fish migration and water quality.
- High Initial Costs: Construction of dams and reservoirs is expensive and time-consuming.
- Displacement of Communities: Local populations may need to be relocated due to flooding of large areas.
- Flood Impacts: When dams are put in place it can cause the loss of flood-lands and nutrients that would have once been given to soils by floods, it also means that if there is a flood it will cause a larger more dangerous flash flood due to the buildup of the water behind the dam

Wind

Wind turbines generate power by using air currents driving a generator
They harvest energy by using blades that catch the wind and cause them to spin driving a turbine
They can be place on and offshore
A wind farm is when many of these turbines are placed together
They need to be in windy areas for maximum efficiency, but they still work even in light breezes
Geologists needed to evaluate the local geology to understand if a place is suitable for building a tower.
They are only used to generate electricity
Pros:
They give clean renewable energy, no constant emissions of greenhouse gas emissions
Cons: They can cause hazards to wildlife around them, alter the view and produce lots of noise, they are hard to recycle once broken

Summary:

- Wind power converts kinetic energy from the wind into mechanical energy, which is then converted into electricity.

How the Energy is Obtained:

- Wind Turbines: Kinetic energy from the wind turns the blades of a turbine, converting wind energy into mechanical (rotational) energy.
- Gearbox and Generator: A gearbox increases the rotational speed, and a generator converts this mechanical energy into electrical energy.

How it is Stored:

- Batteries: Store excess electricity generated during high wind periods for use when wind speeds are low.
- Pumped Hydro Storage: Excess electricity is used to pump water to a higher elevation, where it can be released to generate electricity during demand peaks.

How it is Transported:

- Transmission Lines: Electricity from wind farms is sent to the grid and distributed to consumers.

Pros:

- Clean and Renewable: Wind is a sustainable energy source with no emissions during operation.
- Low Operational Costs: After installation, wind turbines have low maintenance and operational expenses.
- Land Use Efficiency: Wind farms can coexist with agricultural land, providing dual land use.

Cons:

- Intermittent Energy Source: Wind is variable and can be unpredictable, requiring backup power or storage solutions.
- Visual and Noise Impact: Wind turbines can be seen as unsightly and generate noise, impacting nearby residents.
- Wildlife Impact: Turbines can pose a threat to birds and bats.

Solar

Every second the sun is sending large amount of solar radiation toward the planet
This solar radiation is the most abundant source of ambient energy
There are two main ways of harnessing heat energy
One is to use solar collectors to transform light into heat, this heat then drives steam turbines
Another way is to use solar panels
Solar panels use photovoltaic cells to turn light into electricity by stripping atoms of their electrons, creating an electric current
It is a very clean prosses but not very efficient
There needs to be a region with lots of sunlight for it to be effective
It requires a lot of components to be extracted to be built
Pros:
clean renewable energy, no continuous emissions or greenhouse gases, they are able to be use for individual households
Cons: They are time dependant, use up large land space

Summary:

- Solar power converts sunlight into electricity using photovoltaic cells or solar thermal systems.

How the Energy is Obtained:

- Photovoltaic (PV) Cells: Convert sunlight directly into electricity using semiconducting materials.
- Solar Thermal Systems: Use mirrors or lenses to concentrate sunlight to heat a fluid, generating steam to drive a turbine and produce electricity.

How it is Stored:

- Store electricity generated during the day for use at night or during cloudy periods, ensuring a continuous power supply.
- Thermal Storage: Heat is stored in materials like molten salt, which can be used to produce electricity when sunlight is not available.

How it is Transported:

- Transmission Lines: Electricity from solar farms is fed into the grid and transported to consumers through high-voltage lines.

Pros:

- Abundant and Renewable: Sunlight is a vast and inexhaustible resource.
- Reduces Greenhouse Gas Emissions: Solar power generation does not produce CO_2 during operation.
- Low Operating Costs: Once installed, solar systems require minimal maintenance and operational expenses.

Cons:

- Intermittent Energy Source: Dependent on weather and time of day, requiring storage solutions or backup systems.
- Land Use: Large areas are needed for solar farms, which can impact land availability for other uses.
- High Initial Costs: Installation of solar panels and thermal systems can be expensive.

Geothermal Energy

Summary:

- Geothermal energy uses heat from the Earth's interior to generate electricity, providing a reliable power source.

How the Energy is Obtained:

- Geothermal Plants: Drill into the Earth to access heat stored in rocks and water. This heat is used to produce steam, which drives turbines to generate electricity.

How it is Stored:

- Thermal Storage: Hot water or steam can be stored in underground reservoirs and used when needed.

How it is Transported:

- Pipelines: Transport hot water or steam from the geothermal source to the power plant.
- Transmission Lines: Electricity generated is fed into the grid and transported to consumers.

Pros:

- Reliable Power Supply: Provides a constant and stable energy output.
- Low Greenhouse Gas Emissions: Minimal emissions compared to fossil fuel plants.
- Small Land Footprint: Geothermal plants require less land compared to solar and wind farms.

Cons:

- High Initial Costs: Drilling and constructing geothermal plants are capital-intensive.
- Geographical Limitations: Only viable in regions with geothermal activity, such as volcanic areas.
- Potential Release of Harmful Gases: Deep drilling can release gases like hydrogen sulphide.

Waste-to-Energy

Summary:

- Waste-to-energy processes convert waste materials into electricity, reducing landfill waste and providing continuous power.

How the Energy is Obtained:

- Incineration: Burning waste generates heat, which is used to produce steam that drives turbines to generate electricity.
- Anaerobic Digestion: Organic waste is broken down by bacteria in the absence of oxygen to produce biogas, which can be used to generate electricity.

How it is Stored:

- Biogas Storage: Biogas produced during anaerobic digestion can be stored in tanks for later use.
- Thermal Storage: Heat generated from incineration can be stored and used to produce electricity when needed.
- Waste Storage: The waste used for burning can be stored for burning at a later date

How it is Transported:

- Pipelines: Transport biogas to power plants for electricity generation.
- Transmission Lines: Electricity generated from waste is fed into the grid and transported to consumers.

Pros:

- Reduces Landfill Waste: Converts waste materials into usable energy, reducing the volume of waste in landfills.
- Continuous Power Supply: Can provide a steady supply of electricity, as waste is constantly generated.
- Not Location Sensitive: Can be implemented anywhere there is a consistent waste supply.

Cons:

- Potential Air Pollution: Incineration can produce harmful emissions, requiring advanced filtration systems.
- High Initial Costs: Building waste-to-energy plants can be expensive.
- Requires Consistent Waste Supply: Reliable energy generation depends on a continuous supply of waste materials.

Mineral deposits

A mineral resource is a concentration of material minerals in the earths crust that have a greater abundance than average
There are two types of mineral resources metals and non-metals
An ore deposit is a mineral deposit that is concentrated elements that are able to be used to make a profit
In order to be minable and extractable an element needs to be concentrated into an ore of sufficient grade (% concentration compared to waste rock)

An ores grade and worth of mining is dependent on the economy
This makes an ore an economic term
We can also mine minerals such as halite, limestones and gemstones
Silicate mineral are poor ore minerals

Ores do not occur uniformly through rocks of the crust. If they did, we would not be able to extract them economically.
Fortunately for humanity, geologic processes concentrate these minerals in ore deposits, economically significant occurrences of ore.
Geologists distinguish among many different kinds of ore deposits, which differ from one another in terms of which ore minerals they contain and which kind
(Earth: A Portrait of a Planet)

Useful Link:
Minerals Downunder

Ore Grade

Ore grade refers to the concentration of the desired metal within the ore rock, typically expressed as a percentage or in grams per ton (g/t).
Higher ore grades indicate a higher concentration of the target metal, which generally translates to greater economic value and profitability.
Different minerals contain varying amounts of the desired metal. For example, gold ore is often measured in grams per ton, while copper ore is measured as a percentage.
High-grade ores are more valuable because they yield more metal per ton of ore, reducing processing costs and increasing potential returns. Conversely, lower-grade ores require more extensive processing to extract the same amount of metal, often increasing overall costs.
The value of ore grades can be influenced by market prices of metals. Higher-grade ores are more desirable when metal prices are high, while lower-grade ores might still be economically viable if metal prices rise sufficiently.
Accurately determining ore grade is crucial for exploration and mining operations, as it affects decisions regarding the feasibility and profitability of a mining project.

Ore Volume

Ore volume refers to the total amount of ore within a deposit, which is assessed through drilling and sampling.
Drill holes are used to intersect the ore body and measure its thickness and extent. The data from these drill holes are then used to estimate the volume of ore.
The volume of ore is often estimated by interpolating data between drill holes to create a three-dimensional model of the ore body. This model helps in calculating the total volume and tonnage of ore.
The accuracy of ore volume estimates improves with more frequent and strategically placed drilling. Detailed drilling can provide a more reliable estimate of the ore body's size and grade.
Accurate volume estimation is essential for determining the economic viability of a mining project. It impacts feasibility studies, mine planning, and resource valuation.
The volume of ore influences the scale of mining operations. Larger volumes can justify larger and more expensive mining setups, while smaller volumes might require more cost-effective solutions.

Ore deposit and waste

Mining involves extracting not only ore but also non-ore material known as waste rock or overburden. This waste material is the rock that surrounds or lies above the ore deposit and must be removed to access the ore.

Excessive waste rock increases the costs associated with mining and processing. Managing and disposing of waste can be expensive, and inefficient waste management can significantly impact the overall project economics.
The ratio of waste rock to ore is a critical factor in determining the economic viability of a mining project. A higher waste-to-ore ratio means more waste needs to be handled for each ton of ore extracted, which can affect profitability.
The cost of removing and managing waste must be balanced against the value of the ore. If the cost of handling waste becomes too high, it may outweigh the benefits of the ore extracted.
Higher-grade ores can help offset the costs of waste management, as they yield more metal per ton of ore. Conversely, lower-grade ores with higher waste-to-ore ratios may require more efficient waste management strategies to remain economically viable.
For underground mining, the increased costs associated with depth, safety, and ventilation must be justified by the value of the ore extracted. High-grade ore can make underground mining more economically feasible, as the higher value per ton of ore can offset the additional costs.
Evaluating whether the increased value of high-grade ore can offset the higher costs of underground mining is crucial. Proper feasibility studies and cost-benefit analyses are essential to ensure that the project remains economically viable.
Waste management practices have long-term environmental implications. Sustainable practices and reclamation plans are essential to minimize the environmental footprint of mining operations.

Open-Pit vs. Underground Mining:

- Open-Pit Mining: This method is generally more cost-effective, especially for shallow ore bodies. It involves removing large quantities of waste rock to expose the ore, which can result in significant waste production.
- Underground Mining: Used for deeper ore deposits, this method is more expensive due to the need for complex excavation and support systems. It generates less surface waste but creates substantial underground waste.

Mining is important

Mining is not a new process, it has been continuously happening since the bronze age
Nowadays we as a society consume 30 million tons of copper a year
To maintain our usage of resources without recycling old metals we open dozens of new mines each year
After mining rocks we are left with waste rocks, these waste rocks are left behind causing environmental problems
It is important to rehabilitate a site after mining, restoring it to its former condition
This is often impossible to fully restore an environment to its former condition
Laws and regulations which drive up the price of ore and may results in loss of jobs

Where are mineral deposits

Geological processes that concentrate minerals are a common occurrence
The processes that concentrate minerals into ore deposits are even rarer
The distribution of ore deposits is vey uneven
Critical minerals are the rarest type of mineral, they are very rare but are essential resources for our day-to-day life
These critical minerals include rare earth elements, platinum and other elements
They have large economic power due to their abundance and price

Cumulates

Minerals containing elements of economic value are present in all igneous rocks but they are in too low of a concentration to be economical

Minerals within igneous rocks can be concentrated via the settling process so it can be mined
Cumulate sulphide deposits are an example and they make up around 60% of the worlds nickel production

Pegmatites

Pegmatites are a course grained igneous rock that are formed during the latest stage of cooling
They form from waters that separate from magmas in the late stages of crystallisation
They from as veins of minerals in the fractures around igneous intrusions
They are concentrated amalgamations of the elements that aren't incorporated into the rest of the mineral structure such as lithium and beryllium

Hydrothermal deposits

Hydrothermal deposits are deposits formed by hydrothermal fluids, water that has been heated by intrusions
The heated fluids dissolve elements with a high solubility and cool down in a mineral deposit
They often form at MOR's, Subduction boundaries and near plutons

There are 5 main types of hydrothermal deposit

- Porphyry Deposit: a deposit made up of small veins in altered host rock
- Skarn Deposit: a deposit formed by contact metamorphism cooking country rocks
- Volcanic Massive Sulphide Deposit: where fluids deposit ore near surface
- Sedimentary Exhalative: This is the same prosses as the above VMS, but sedimentary instead
- Epigenic Deposit: A type of deposit not associated with direct igneous heating

Sedimentary deposits

Formed from sedimentary processes and in sedimentary rocks (either detrital or chemical)
There are 5 main sub-types of sedimentary deposits
Placer deposits are deposits concentration by water and gravity
A BIF (Banded Iron Formation) is a type of deposit produced by oxidation of Fe
An Evaporite is a deposit created from precipitation after evaporation of water
Laterite & Bauxite are deposits formed from weathering that concentrate elements such as Fe and Al

How and where to find ore deposits

Knowing how where and when deposits form help finding new ones
Many of the different types of deposits occur in direct or indirect (e.g. placers) relationship with igneous rocks, hence most deposits can be found near:

- Subduction zones
- Continental rift
- Hot spots
- Mid-oceanic ridges
- BIFs occur in old Archean rocks
- Bauxite form from weathering of igneous rocks in tropical environments

Companies employ exploration geologists to survey potentially prospective regions using a variety of geophysical (large scale) and geochemical (sample scale) methods to look for key indicators.
Once an area is deemed prospective then open pit or underground mining operations can begin

Stages in exploration

Exploration is the longest and riskiest stage when establishing a mine
For one successful mine to be established many are abandoned
Early exploration identifies target areas that might have deposits

Mid stage exploration investigate each target and determines if each may be viable
Late exploration looks in detail at one target to determine ore value and plan mines if it proves economic
Main steps are, discovery, Inferred, Indicated, Measured resources

Types of Exploration

There are many methods of ore exploration, they can be grouped into 3 main categories Geophysical, Geochemical and Remote sensing
Geophysical involves using physical properties of the rock to determine ore deposits locations
Geochemical involves using the chemical properties of samples to determine where deposits are
Remote sensing uses imagery to show images of the rock which are used to determine the location of ore deposits
Geophysical contains:

- Magnetics
- Electromagnetics
- Gravity Surveys
- Seismic Surveys

Remote Sensing:

- Aerial Photography
- Satellite Spectrophotometry

Magnetics

An aircraft flies in a grid patter carrying a magnetometer
A magnetometer records the changes in the strength of the earth's magnetic field
Anomalies relate to the presence or absence of magnetic minerals
This data is then interpreted for the anomalies to establish potential deposits
If there is a low point in the data, then it may be a hydrothermal activity as it destroys magnetic minerals
If there is a high point in the data, then it may be high in sulphides and iron deposits containing magnetic minerals

Electromagnetics

This is similar to a magnetic survey an aircraft carries a Magnetometer
They also carry an Induction loop that generates a strong primary field
Primary magnetic field induces a secondary magnetic field withing conductive ores.
The Magnetometer detects changes in the secondary magnetic field generated in more electrically conductive minerals
Conductive minerals include sulphides such as nickel sulphide or hydrothermal gold or large metal deposits, this can also be used to find fresh soil water.

Gravity Surveys

The higher the mass the more gravity.
The earth has fluctuations in the gravity field depending on what is below
Aircraft or satellites fly over a region or grid pattern
A gravitometer detects the strength of earths gravitational field
Dense rocks concentrate more mass in a location
More mass creates an increase in the gravitation field strength
It can locate the deepest ores but it is low in resolution

More dense rocks shows us a positive anomaly including massive nickel sulphide deposits, Igneous intrusion that may form hydrothermal deposits, Large iron ore deposits that are higher density then BIF

Seismic Surveys

Seismic surveys are conducted in sedimentary basins to study the subsurface geology structures and geology
Seismic waves created by vibration trucks propagate through the earth then geophones detect any reflected seismic waves.
Rocks with contrasting densities reflect waves allowing geological interpretation of the structures below
You can also have marine seismic surveys that operate with the same principals as terrestrial ones but the equipment is changed with an airgun creating vibrations in the water and hydrophones detect the waves

Aerial photography

Aerial photographs capture visible light reflected off the Earth's surface.
They are useful for Identifying soil and rock types, Observing surface features, Detecting geological structures such as faults and folds
This Helps in preliminary geological surveys and mapping surface geology.

Satellite spectrophotometry

Hyperspectral imaging records a wider range of electromagnetic radiation.
It records from Infar-Red to Ultra-Violet
It records a more detailed and specific analysis of the surface
All digital images are captured using a Charged Coupled Device, the same device in a digital camera.
These may be sensitive to different wavelengths of light
Different substances including different minerals reflect specific wavelengths
By analysing the reflected light from a hyperspectral image using computers, geologists can identify different rock and sediments types at the surface.
This can help identify any deposit at the surface or geochemical signals of a deposit below, or structures that host ore deposits.

Soil sampling

Deposits my weather and no longer be visible at the surface
Soil samples cab be collected on a grid analysed to look for anomalies in their concentration.
The top signals are geochemical anomalies are chemical signals that stand out to the area
Metal concentrations might be useful to find buried deposits
There might be other elements that are linked to the ore formation that could indicate a target
This can also figured out by Stream and Lake sediment sampling , Groundwater trace element composition ,Weathered outcrops

Drilling

Once there is a target, you can use drilling until there is confirmation of the interpretation
The more it is sampled the better you can understand the value and the cost of extracting
Factors that need to be investigating, Volume, grade, depth and waste, price.
Drill rigs drill down through the rock and brings back a core sample
Geologists keep truck of the rock types drilled though by creating a drill log
A diamond drilled core is a intact cylinder of rock they can be examined and analysed
Geologists keep track of the rock types by creating a drill log

Mining and the environment

You probably know by now but mining isn't very goof for the environment

- Mining leaves a big footprint on the land, in the form of either big holes or tailing "mountains"
- Mining exposes sulphides which react with rain water producing acid runoff.
- Mining operations require leaching acids which can also escape in the environment and groundwater
- Ore processing uses toxic chemicals and heavy metals that can be washed away by rain back into the groundwater
- Mining uses a lot of energy and creates a big carbon footprint
- Using clean tech is doable, but obviously costs a lot more

Hydrological Impacts of Mining

Mining activities can significantly alter local hydrology, leading to various impacts:

- Pit Dewatering: Pumping out water from mining pits can lower the water table and affect nearby water sources.
- Groundwater Drawdown: Extracting groundwater from aquifers can lower water levels, affecting wells and natural springs.
- Acid Mine Drainage: Acidic runoff from mining areas can leach heavy metals and pollutants into surrounding water bodies.
- Cyanide Heap Leaching: Cyanide used in gold extraction can leach into the environment, posing risks to aquatic life and human health.
- Tailings Management: Waste rock and tailings can contaminate groundwater and surface water with heavy metals.

Mitigation Measures:

- Aquifer Recharge: Replenish groundwater by pumping treated water back into aquifers or using other methods to stabilize water levels.
- Water Treatment: Implement water treatment systems to remove contaminants before releasing water back into the environment.
- Erosion Control: Use barriers and vegetation to reduce soil erosion and prevent sedimentation of water bodies.

Biospheric Impacts of Mining

Mining can have profound effects on the biosphere, including:

- Loss of Biodiversity: Destruction of habitats can lead to the extinction or displacement of plant and animal species.
- Ecological Disruption: Changes in land use and resource availability can disrupt ecological balances and food chains.
- Soil and Water Contamination: Pollutants from mining activities can degrade soil and water quality, affecting plant and animal health.
- Altered Species Distribution: Changes in habitat conditions can force species to migrate, potentially leading to ecosystem imbalances.

Mitigation Measures:

- Habitat Restoration: Conduct habitat restoration projects to reintroduce native species and rehabilitate disturbed ecosystems.

- Monitoring Programs: Implement regular monitoring to assess the health of local flora and fauna, and take action to address any negative impacts.

Atmospheric Impacts of Mining

Mining activities can also affect the atmosphere in several ways:

- Air Pollution: Mining operations release particulate matter, sulphur dioxide, and other pollutants, which can degrade air quality and harm respiratory health.
- Greenhouse Gas Emissions: Energy use in mining processes contributes to carbon dioxide and methane emissions, exacerbating climate change.
- Climate Change: Increased greenhouse gas emissions can lead to global warming and altered weather patterns.
- Acid Rain: Emissions of sulphur dioxide and nitrogen oxides can lead to acid rain, which damages vegetation, water bodies, and infrastructure.

Mitigation Measures:

- Air Quality Controls: Implement technologies such as dust collectors and scrubbers to reduce air pollutants.
- Greenhouse Gas Reduction: Optimize mining operations to lower energy consumption and switch to renewable energy sources.
- Atmospheric Monitoring: Regularly monitor air quality and atmospheric conditions to identify and address pollution sources.

Key Baseline Data

Understanding the original environment before mining activities is crucial for assessing and managing their impacts. This baseline ecological data serves as a reference to evaluate changes and hold mining companies accountable. Key baseline data includes:

- Temperature: Records of local temperature patterns.
- Rainfall and Flooding: Historical data on precipitation and flood events.
- Population: Information on local human populations and settlements.
- pH of Water: Measurements of water acidity or alkalinity in local water bodies.
- pH of Soil: Soil acidity or alkalinity data.
- Metal Concentrations in Water: Levels of heavy metals and other pollutants in water sources.
- Groundwater Levels: Depth and variations in groundwater levels.
- Biodiversity: Types and numbers of species present in the area.
- Water Flow: Patterns of surface water movement.
- Dust Levels: Baseline measurements of airborne dust concentrations.

Mine rehabilitation

As mentioned above mine rehabilitation is an efficient way to lower the impacts of mining on all 4 spheres on the environment (Geo, Atmos, Hydro, Bio)
Rehabilitation is when a mine site is restored as best as possible to its original conditions before mining
This requires collecting the key baseline data and returning the environment to this state
To do this mining companies work with government authorities to develop comprehensive rehabilitation plans.
These plans show how the company should return the resulting landform to a safe and stable condition (reintroducing plant and animal species in a manner consistent with the surrounding landscape.

This means that the land can be returned to indigenous owners looking pristine
In NSW, each mine is required to lodge a rehabilitation security deposit covering the full cost of the rehabilitation plan in case the company declares bankruptcy
This mine rehabilitation creates tons of new jobs

Anthropogenic climate change

What is anthropogenic climate change

The climate is getting warmer globally with sea level rising, icesheet melting and hottest years on record.
That has never been open to debate it's just data and observations.
The debate was if human were the cause or if it was a natural process
Today there is almost no debate on whether it is a natural occurrence even large fossil fuel companies have now reluctantly accepted that theory

Important points

The global temperature is about 1.1 °C warmer than in the 1800's.
Fastest rise since 70's.
Continuing on the current path, we would reach + 4.4 °C in 2100.
Greenhouse gases are at the highest level in the last 2.2 Myr (but "low" compared to hothouse Eocene (> 1,000 ppm)
Currently CO_2 concentration 420 ppm (0.042%)
Artic surface temperature have risen twice as fast

Earth Energy Budget

The Earth's Energy Budget refers to the balance between the energy Earth receives from the Sun and the energy it radiates back into space.
This balance is crucial for maintaining the planet's temperature and affects weather patterns, climate, and overall habitability.
The net transfer of solar energy to Earth's surface is influenced by its passage through atmosphere, including factors like impeded of ultraviolet radiation to Earth's surface due to Its interaction with atmospheric ozone, and by the physical characteristics of Earth's surface including albedo.
The Sun's energy drives the water cycle by causing the evaporation of water from Earth's surface, which then forms clouds and eventually returns as precipitation.
This energy also causes various transformations on Earth, including the warming of the surface, the formation of wind and ocean currents, and the growth of plants through photosynthesis.
The delicate balance of Earth's energy budget affects life by maintaining a stable climate that supports diverse ecosystems.
An imbalance can lead to climate change, which impacts species survival and human activities.

Albedo and the energy budget

Albedo can reflect incoming sunlight
This happens through the reflection of light
Polar ice caps and dark land surfaces absorb sunlight differently.
Ice caps reflect most sunlight, which contributes to cooling, while dark land surfaces absorb more sunlight, leading to warming.
Clouds play a dual role in modifying the Earth's energy balance.
They can reflect sunlight, which cools the planet, or trap heat, which warms it.

If the amount of energy leaving the planet exceeds the amount coming in, the Earth would cool down, potentially causing global temperature drops and changes in climate patterns.

How Climate Change Leads to a Snowball Effects and unpredictable changes

Changes in factors such as sea ice, methane clathrates, desertification, cloud formation, and oceanic CO_2 solubility can significantly alter the energy balance of the earth, if this is altered past a certain point then the natural recovery systems will not be able to fix it.
This change in climate can also lead to unpredictable effects on the climate
For example, less sea ice results in more sunlight being absorbed, while melting methane accelerates the increase the greenhouse effect.
Desertification can lead to more reflection of solar radiation which could cool the planet but it also leads to larger areas without vegetation coverage reducing CO_2 Consumption and
and increased cloud cover could either cool or warm the planet depending on cloud types and altitude.

Evidence for global warming

We have observational evidence of global warming thanks to satellite data:
This data shows events such as:

- Shrinking ice sheets [Greenland is losing 279 billion tons of ice per year]
- Retreat and disappearance of glaciers
- Decrease of snow cover
- Sea level rise [rose by 20 cm in the last 100 years]
- Decreasing sea ice → modification of thermohaline circulation
- Increase of extreme events
- Ocean acidification
- Melting of permafrost [CH4 + viruses]

The Greenhouse Gasses we emit

Greenhouse's gases are gasses in the atmosphere that let sunlight go through but don't let the heat radiating back from the ground escape
Type of greenhouse gases we release:

- Carbon dioxide from burning fossil fuels
- Methane from agriculture and livestock
- Nitrous oxide from agriculture
- Fluorinated gases from industrial processes
- Water vapour

Some gasses are more potent than other and are defined by their Global warming potential (over 100 years) this is a relative unit to carbon dioxide equivalent

- CO_2 = 1 / Methane = 28 / Nitrous oxide = 265 / F-gases > 1000

CO_2 equivalent is a metric used to compare the impact of different greenhouse gases based on their global warming potential.
It allows for a standardized measure of their contributions to global warming.
Carbon dioxide (CO_2) is the most significant greenhouse gas, with major sources being fossil fuel combustion and deforestation.
Methane (CH_4) is another potent greenhouse gas, primarily released from agriculture and livestock.
Hydrofluorocarbons (HFCs) and chlorofluorocarbons (CFCs) are synthetic gases used in refrigeration and air conditioning, which also contribute to warming.
Nitrous oxides (N2O) come from agricultural and industrial activities.

The gases are ranked by their contribution to anthropogenic climate change, with CO_2 generally being the most significant, followed by methane, nitrous oxides, and HFCs/CFCs.

Why do we release GHGs

In total humanity released of greenhouse gases is 51 billion tons CO_2 in 2021
Biggest source of all is the creation of energy for industry (this includes mining)
Second is agriculture and livestock as a whole (livestock, soils, burning)
Third is energy used in buildings (heating and cooling, light)
Forth is energy used in transportation (fuel)
Other large sections of pollution are

- Fugitive emissions (8%) – accidental leakage from fossil fuel industry
- Industrial processing (5%) of cement + chemicals & petrochemicals
- Waste (3%): throwing stuff away that rot (wasting food)
- Deforestation and crop burning (2%): prevent carbon storage.

Particulates

Particulates are tiny particles or droplets suspended in the atmosphere.
They are categorized into natural particulates, such as volcanic ash and dust, and anthropogenic particulates, such as those from industrial processes and vehicle emissions.
Particulates can influence climate by both increasing and decreasing atmospheric warming.
They can absorb sunlight, leading to warming, or reflect sunlight, resulting in cooling.
Additionally, particulates can reduce warming at Earth's surface by blocking sunlight.
Geoengineering using particulates involves injecting aerosols into the atmosphere to reflect sunlight and cool the planet down.
One argument in Favor of this approach is its potential to mitigate global warming relatively quickly.
However, opposition arguments include the potential unintended consequences and the uncertainty of its long-term effectiveness.

Australia's emissions

Australia emitted 494 Million tons of CO_2 in 2021 making us one of the top producers in the world per person
Our emissions are slowly getting lower due to:

- COVID restrictions affecting transport
- Better control of fugitive emissions
- Reduction of emission from electricity

But in certain sectors we are still increasing such as:

- Increase in agriculture sector due to methane from cattle

What happens to Green House Gases in out atmosphere

Methane has a residence time in the atmosphere of 12.5 year so is quickly removed by natural chemical reactions
Some methane is transformed in CO_2 and trapped in soils in a reaction with oxygen $CH_4 + 2\ O_2 = CO_2 + 2\ H_2O$
However we are putting more methane into the atmosphere that can be released, and this is causing the concentration to keep increasing
Nitrous oxide has a residence time of 121 years and is destroyed in the stratosphere

The F-gases vary widely in residence time from few weeks to more than a millennium
Water vapor is also a potent greenhouse, but it's cycle in the atmosphere is extremely short due to the water cycle.

What happens to CO_2 across the planet

Usually CO_2 from the atmosphere is dissolved in the ocean or is absorbed by plants, soils and rock formations
Due to our large production of CO_2 we are producing more than can be absorbed so the ocean and plants can't keep up.
By absorbing CO_2 oceans makes the water acidic which is unhealthy for marine life (acidity has increased by 30 % since 1800's)
The land has become less efficient since the increase of temperature has made it becomes dryer and contains less nutrients
Deforestation also removes a major carbon sink from the carbon cycle

Lithospheric absorption of CO_2

Lithospheric absorption of CO_2 is when carbon dioxides goes into the formation of carbonates and sedimentary rocks
The weathering of these rocks uses up the carbon dioxide in the rock by dissolving the rock and reacting with the weathering product
This makes it one of the rare negative feedback effects where the more CO_2 is added into the atmosphere, the faster chemical weathering happens, which then lowers CO_2 levels back down again.
Currently the rock cycle absorbs around ~ 1 Gt CO_2 / year while emitting 51 Gt / year

Effects of global warming

Global warming has multiple effects on us, the environment and the planet.
Some of the most prevalent of these effects are:

- Overall increase in temperatures causing heat waves more frequent and longer, this could cause heat strokes, water shortage, increased sickness.
- More frequent and severe storms and cyclones which has large impact on people and animal populations through deaths, as well as huge financial costs
- An increase in precipitation in wet regions and decrease in dry regions
- An increase in droughts causing water shortage, wind erosion, desertification, wildfires
- A loss in ice sheets and a rise in the sea level causing flooding, threatening coastal areas with erosion and saltwater intrusions.
- An increase in the acidity of the ocean killing plankton, plants, algae and bacteria in ocean which produce between 50 % and 80 % of the oxygen each year
- An overall loss of species as they cannot adapt to the rapid change in climate
- Less food due to reduction of ideal growing conditions as well as an increase in unpredictable climatic events
- As well as an increase in poverty and displacement due to sea level rise and climatic events

What doe sea level rise look like

Sea level rise occurs due to the melting of ice and the thermal expansion of water
The sea level is not flat and even across the planet it varies with location
This can be both artificial or caused by local tectonics causing vertical motion in the land
Both of these factors add up creating sea level change
As a result of sea level change

- Low-lying islands will be submerged

- Increase flooding in coastal area
- Increase coastal area erosions
- Saltwater intrusions in surface water
- Population displacement

We are already seeing the disappearance of islands in the pacific, [Tuvalu have seen flooding saltwater on cultivated land and in sources of drinking water]

The rise of sea level is caused by three main factors: thermal expansion of seawater due to warming, melting glaciers and ice sheets, and increased ice melt from glaciers.
Storm surges are temporary rises in sea level caused by storms, exacerbated by sea level rise, leading to increased coastal flooding.
Saltwater intrusion occurs when rising sea levels push saltwater into freshwater aquifers, affecting water supply.
Sea level rise impacts coastal geomorphology by causing erosion and altering shorelines and affects nearshore aquatic ecosystems by changing habitat conditions.
Warmer oceans reduce CO_2 solubility, leading to higher atmospheric CO_2 levels and increased warming.
Carbon dioxide is a major greenhouse gas, but other gases like methane and nitrous oxide also contribute significantly.
Clouds have a complex effect on global warming as they can both reflect sunlight and trap heat.

Climate change and Rainfall

Current climate models indicate that rising temperatures will intensify the Earth's water cycle, increasing evaporation. Increased evaporation will result in more frequent and intense storms, but will also contribute to drought over some land areas. As a result, storm-affected areas are likely to experience increases in precipitation and increased risk of flooding, while areas located far away from storm tracks are likely to experience decreased precipitation and increased risk of drought.

Climate change can affect the intensity and frequency of precipitation. Warming oceans increase the amount of water that evaporates into the air. When more moisture-laden air moves over land or converges into a weather system, it can produce more intense precipitation—for example, heavier rain and stronger storms. The potential impacts of heavy precipitation include flood damage, soil erosion, and an increase in flooding risk due to heavy rains, which in turn can lead to injuries, drownings, and other flooding-related effects on communities. In addition, runoff from precipitation can impair water quality as pollutants deposited on land wash into water bodies.

Heavy precipitation does not necessarily mean the total amount of precipitation at a location has increased—just that precipitation is occurring in more intense events. However, changes in the intensity of precipitation, when combined with changes in the time intervals between precipitation events, can also lead to changes in overall precipitation totals.

Species Distribution and Climate Change

Abiotic factors influencing habitat range include temperature, salinity, and pH levels.
Within an optimal range, factors such as food availability and predation influence population size.
Rising ocean temperatures and increased CO_2 levels can alter habitat ranges and reduce population sizes by affecting species' physiological limits and food sources.
The environment in which an organism lives is its habitat, The habitat may not be homogeneous in its quality.
The environment in which an organism (or species) lives (including all the physical and biotic factors) is its habitat.

Within any habitat, each species has a range Of tolerance to variations in its environment. Within the population, individuals will have slightly different tolerance ranges based on small differences in genetic make-up, age, and health.
The wider an organism's tolerance range for any one factor (e.g. temperature) the more likely it is that the organism will survive variations in that factor. For the same reasons, species with a Wider tolerance range are likely to be more widely distributed.
Organisms have a narrower optimum range within which they function best.
This may vary seasonally or during development.
Organisms are usually most abundant where the abiotic factors are closest to the optimum range.

Climate Change and Crop Yields

Climate change poses significant challenges to global food production across multiple dimensions. While higher CO_2 levels may initially boost crop yields through enhanced photosynthesis and improved water-use efficiency, this benefit is counterbalanced by the negative impacts of increased temperatures, which can cause heat stress, shorten growing seasons, and reduce crop yields. Additionally, changing rainfall patterns can lead to water scarcity or excess, further complicating crop production.
The availability of water and nutrients remains a critical limiting factor for plant growth, often outweighing the benefits of increased CO_2.
Moreover, climate change is expected to expand the range and distribution of weeds and insect pests, increasing competition and damage to crops.
The nutritional quality of crops may also decline due to higher CO_2 levels, reducing the concentrations of essential nutrients. In livestock production, heatwaves and droughts can severely impact animal health and productivity, while the spread of parasites and diseases poses additional threats.
Fisheries are similarly affected, with shifts in species distribution, increased disease prevalence, and disrupted reproductive cycles.
Overall, the combined effects of climate change on crops, livestock, and fisheries are a challenge for global food production.
Adaptation strategies, such as developing heat-tolerant crop varieties, improving water management, and enhancing disease monitoring and control, will be essential to mitigate these impacts and ensure food security in the future.

What should we do

We can either go down the American route and ignore it or we can do something about it
Whichever option we choose it will have profound changes for our society

Paris Agreement

Climate change is a problem that effects all nations equally, it is a problem without borders.
Therefore the solution needs to be created and adopted on a worldwide basis
Developed countries emit and have emitted a lot more greenhouse gas emissions than developing countries and so must help all countries to move into a more sustainable future.
We must develop ways to continue our lifestyle while taking climate change into account
The Paris agreement aims to address this problem
It is an international agreement adopted by 193 countries to work against the rise of the climate and cut carbon emissions to net zero.
Net 0 means the amount of greenhouse gas produced and removed from atmosphere is in equilibrium therefore we are not directly effecting the environment

Energy transition

We need to move the economy away from fossil fuels as soon as physically possible

The IEA (International Energy Agency) states we cannot start any new fossil fuel projects if we are to reach net 0 by 2050
Since electricity is needed for every aspect of modern life we need to transition to 100% of our energy coming from low carbon or renewable energy such as:

- solar,
- wind,
- hydropower,
- nuclear
- Hydrogen
- geothermal

Electric vehicles are reliant on this new clean energy grid (Otherwise they are still technically producing CO_2)
To support the future, we need to create a new more efficient and sustainable energy grid
We also need to improve the energy efficiency of all aspects of modern life so we diminish the energy consumption per person while keep our lifestyle relatively similar to today

Mining to enable the energy transition

To enable the transition into a more renewable future we will need metals and mining
Some examples can be found below:

- A standard electric car battery contains 8 kg Li, 35 kg Ni, 20 kg Mn and 14 kg cobalt (6x more metals than petrol vehicle)
- Charging stations and electrics use large quantities of Cu
- Solar panels are made out of Si, Ag and Zn
- Wind turbines are made of Fe, Cu and Al

There is not currently enough production to meet the metal demands of 2050 so we will need to create more mines
This means we will need more investment in mining
This is frowned upon because of environmental, social, and governance considerations of mining development
To solve this problem the mining sector need to commit to environment (e.g. rehabilitation, decrease carbon emissions) to attract more green funding and be seen as the solution to sustainability, not the problem
Metal recycling and product reuse can help

Mine rehabilitation (repeat)

As mentioned above mine rehabilitation is an efficient way to lower the impacts of mining on all 4 spheres on the environment (Geo, Atmos, Hydro, Bio)
Rehabilitation is when a mine site is restored as best as possible to its original conditions before mining
This requires collecting the key baseline data and returning the environment to this state
To do this mining companies work with government authorities to develop comprehensive rehabilitation plans.
These plans show how the company should return the resulting landform to a safe and stable condition (reintroducing plant and animal species in a manner consistent with the surrounding landscape.
This means that the land can be returned to indigenous owners looking pristine
In NSW, each mine is required to lodge a rehabilitation security deposit covering the full cost of the rehabilitation plan in case the company declares bankruptcy

This mine rehabilitation creates tons of new jobs

Carbon sequestration

Reaching net zero requires that we not only reduce carbon emissions but also capture some of the carbon dioxide we have emitted and store it ourselves.

Geological carbon sequestration

Geological sequestration is when carbon is injected into the ground in the form of compressed liquid CO_2 to remove it from the carbon cycle

We can sequestrate carbon to multiple reservoirs

- deep saline aquifers [1,000 – 10,000 Gt CO_2 reservoir]
- depleted oil & gas reservoirs [700-900 Gt CO_2 res.]
- coal beds [150 – 200 Gt CO_2]
- salt beds

To successfully Sequestrate Carbon the trap area needs to have good porosity, a cap layer, no faults and overall, minimal risk of leakage

Storage of CO_2 in basalt in deep sea Igneous formations is also possible; this would artificially alter the basalt creating calcite within it.

The Carbfix experiment (2012) showed that 95 % of CO_2 injected in basalt was solidified in calcite but this would use 25 tons of water per ton of CO_2 sequestrated

Biological carbon sequestration

We can store atmospheric carbon (carbon dioxide) in plant life, forests, soils and aquatic environments.

The earths soils contain more carbon than vegetation and the atmosphere combined.

Storing carbon in the soil is a good farming practice that improves soil quality

This can be done by:

- Soil tillage, pushing residue and organic matter below the soil
- Clover coverage
- Crop rotation cycles
- Livestock cycles

Certain ground coverings such as grasslands and forests can also help store organic matter in the soils

- If we stop clearing forests it will not only produce CO_2 from combustion but release it from storage in the soil when it is disturbed
- If the wood is cut down we can use the product for construction material so it isn't burned
- We can also regrow harvested forest and grow new forests

Circular Economics

In our current economic system once products have been used up they are thrown into landfill, this wastes resources, energy and causes pollution to the environment through adding plastic to the environment and the leeching of chemicals into soils

A circular economy is a type of economy where the consumption of goods is slowed as well as goods that are disposed of are recycled

The goal of this economic system is to extend the lifetime of products by using them for longer before replacement and designing them to a higher standard of quality so they don't break as often and are recyclable if they do break

Transitioning into a circular economy would help to mitigate the carbon dioxide emissions that we produce as we would consume and produce less than we currently do

References, Markers and Sources

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Link available soon

EES WACE Study Planner
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